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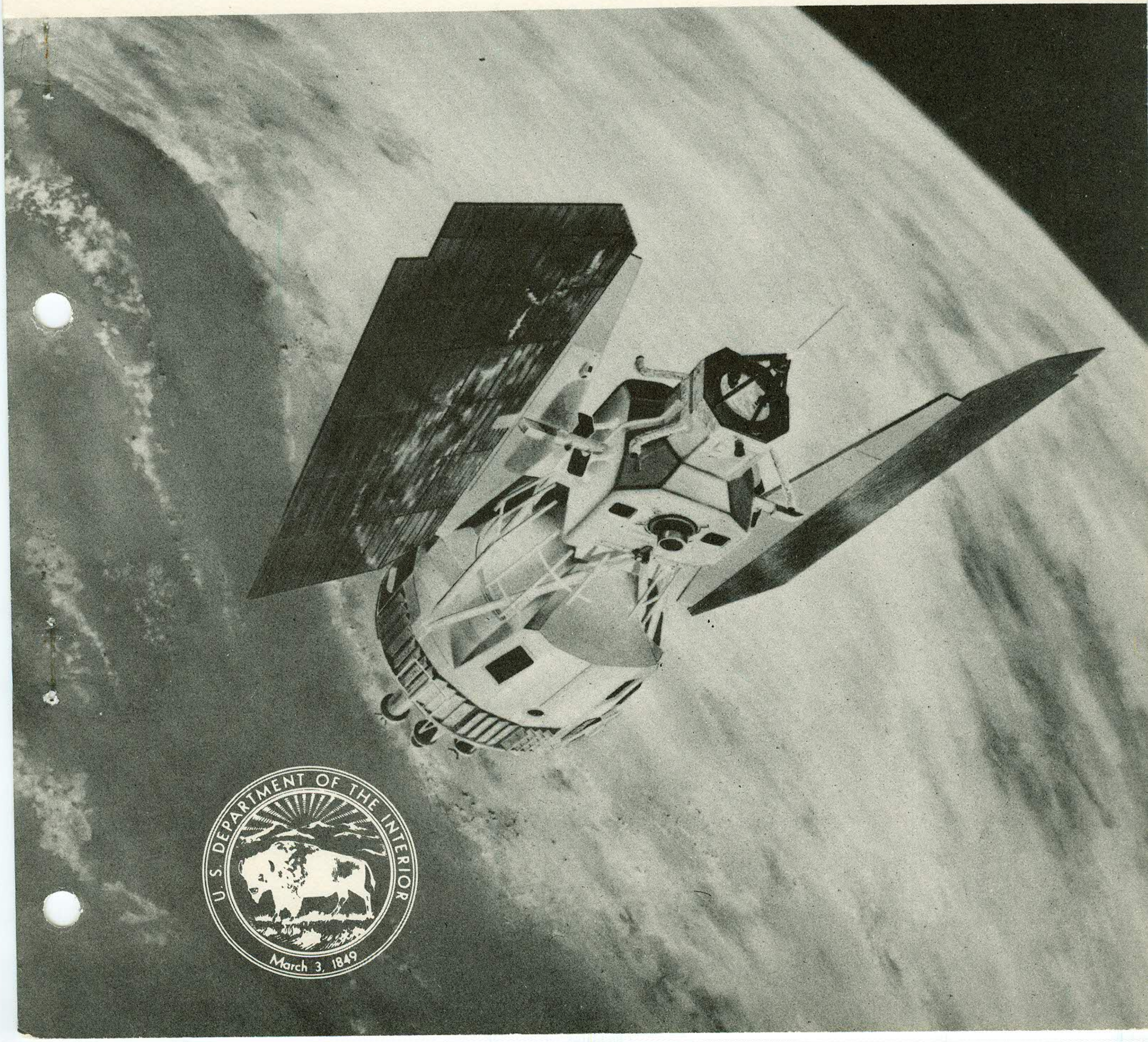
MANUAL ON CHARACTERISTICS OF LANDSAT COMPUTER-COMPATIBLE TAPES PRODUCED BY THE EROS DATA CENTER DIGITAL IMAGE PROCESSING SYSTEM

UNITED STATES
GEOLOGICAL SURVEY

NATIONAL AERONAUTICS
AND SPACE ADMINISTRATION



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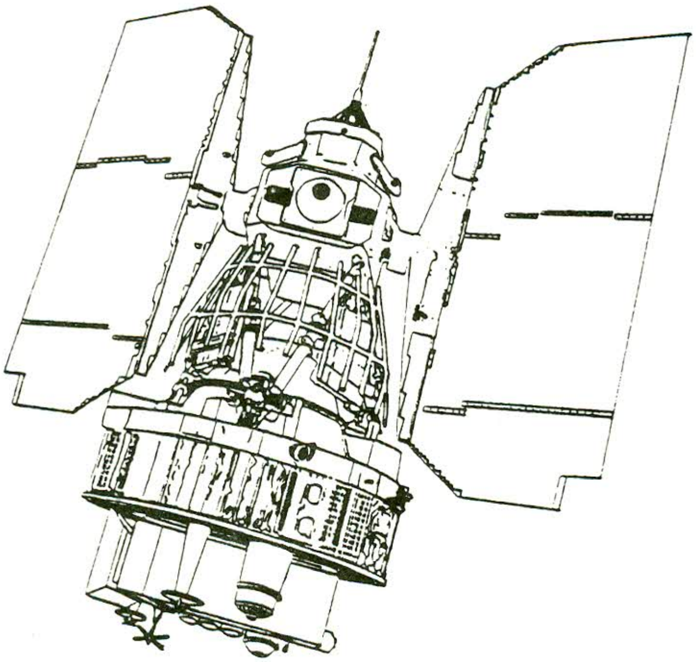
REVISED, DECEMBER 1978



VERSION 0.0

COMPILED BY PATRICK F. HOLKENBRINK

UNITED STATES GEOLOGICAL SURVEY 1978

UNITED STATES DEPARTMENT OF THE INTERIOR

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GEOLOGICAL SURVEY

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For sale by the Superintendent of Documents, U.S. Government Printing Office
Washington, D.C. 20402
Stock Number 024-001-03116-7

LIST OF EFFECTIVE PAGES

Original pages are indicated by a zero, and other pages are identified by the change number in effect for those pages. Insert latest change pages; destroy superseded pages. Dates of issue for original pages and change pages are as follows:

Original: 15 December 1978

The total number of pages in this document is 78, consisting of the following:

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ii	0
A	0
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MANUAL ON CHARACTERISTICS OF LANDSAT COMPUTER-COMPATIBLE TAPES PRODUCED BY THE EROS DATA CENTER DIGITAL IMAGE PROCESSING SYSTEM

COMPILED BY PATRICK F. HOLKENBRINK[1]

INTRODUCTION

Landsat data are received by National Aeronautics and Space Administration (NASA) tracking stations and converted into digital form on high-density tapes (HDTs) by the Image Processing Facility (IPF) at the Goddard Space Flight Center (GSFC), Greenbelt, Maryland. The HDTs are shipped to the EROS Data Center (EDC) where they are converted into customer products by the EROS Data Center digital image processing system (EDIPS). This document describes in detail one of these products: the computer-compatible tape (CCT) produced from Landsat-1, -2, and -3 multispectral scanner (MSS) data and Landsat-3 *only* return-beam vidicon (RBV) data. Landsat-1 and -2 RBV data will *not* be processed by IPF/EDIPS to CCT format.

DATA CHARACTERISTICS

SPACECRAFT SENSORS

The image data received and processed by IPF and EDIPS are scanned, or imaged, by the sensors onboard the Landsat spacecraft. Each spacecraft carries two sensor systems: a return-beam vidicon (RBV) camera system and a multispectral scanner (MSS) system. A more detailed description of these sensors is given in Section P of the *Landsat Data Users Handbook, Revised.*

[1]Technicolor Graphic Services, Inc. Prepared for the United States Geological Survey under contract no. 14-08-0001-16439.

RBV CAMERA SYSTEM

On Landsat-3, the RBV system consists of two independent cameras. The ground-area image is stored on the photosensitive surface of the camera tube, which after shuttering, is scanned to produce a video signal output. The shuttered panchromatic cameras produce two side-by-side images rather than three images of the same area as produced by the three independent narrow-band cameras on Landsat-1 and -2. Each camera covers an area 99 x 99 km with an instantaneous field of view of about 19 meters. Each RBV image is referred to as a subscene; the four subscenes that comprise a Landsat scene are labeled A, B, C, and D (fig. 1). The four RBV images approximately coincide with one MSS frame. Figure 2 shows a fully processed RBV subscene with 81 reseau marks (nine rows of nine) on the tube surface.

MULTISPECTRAL SCANNER SYSTEM

The multispectral scanner (MSS) is a line-scanning device that uses an oscillating mirror to continuously scan perpendicular to the spacecraft's orbital path. The MSS's on Landsat-1 and -2 have six detectors in each of four spectral bands, operating in the spectral interval from 0.5 to 1.1 micrometers. These detectors provide outputs that are sampled, digitized, and transmitted to Earth as a continuous strip of image data for each mirror sweep. At GSFC, all data received are reprocessed, framed as individual scenes, and encoded on

HDTs. Figure 3 shows a fully processed MSS scene.

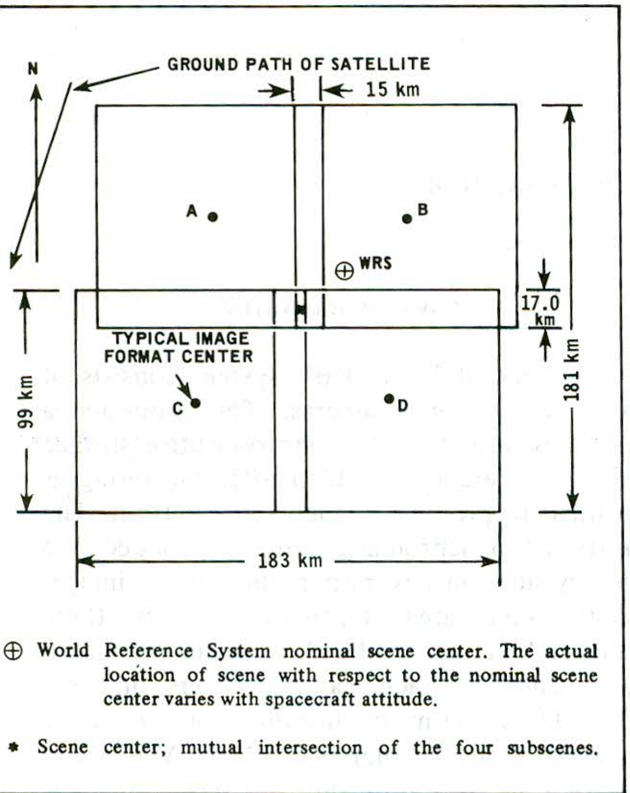


Figure 1.–Format of a fully processed Landsat-3 RBV scene, showing the locations of subscenes A, B, C, and D.

On Landsat-3, a fifth spectral band operates, using only two detectors, in the thermal-infrared region of 10.4 to 12.6 micrometers. Thus, spatial resolution of this band is less than the other four. Because of the reduced sampling rate of the thermal band, as compared with the other four bands, its pixels must be replicated in the unprocessed image array for three across and for three scan lines by the GSFC data processing facility. Figure 4 shows the relationship that allows all bands to have the same number of pixels. This expanded image array is resampled and corrected to produce the standard thermal image. Thus, the replication pattern is not discernable in a fully processed scene.

SCAN LINES

Each image is made up of parallel scan lines that contain a large number of picture elements (pixels). For the MSS, the actual number of these pixels depends on mirror motion and other factors. The greatest deviation for Landsat-1 and -2 is ± seven pixels. The relationship between these pixels and the corresponding ground area is discussed in Appendix F. The distance covered by a scan line varies with the altitude. Experience has shown that the variations have resulted in scan line changes of approximately ± 4 km in the worst case. For RBV, the number of pixels in each scan line is electronically fixed.

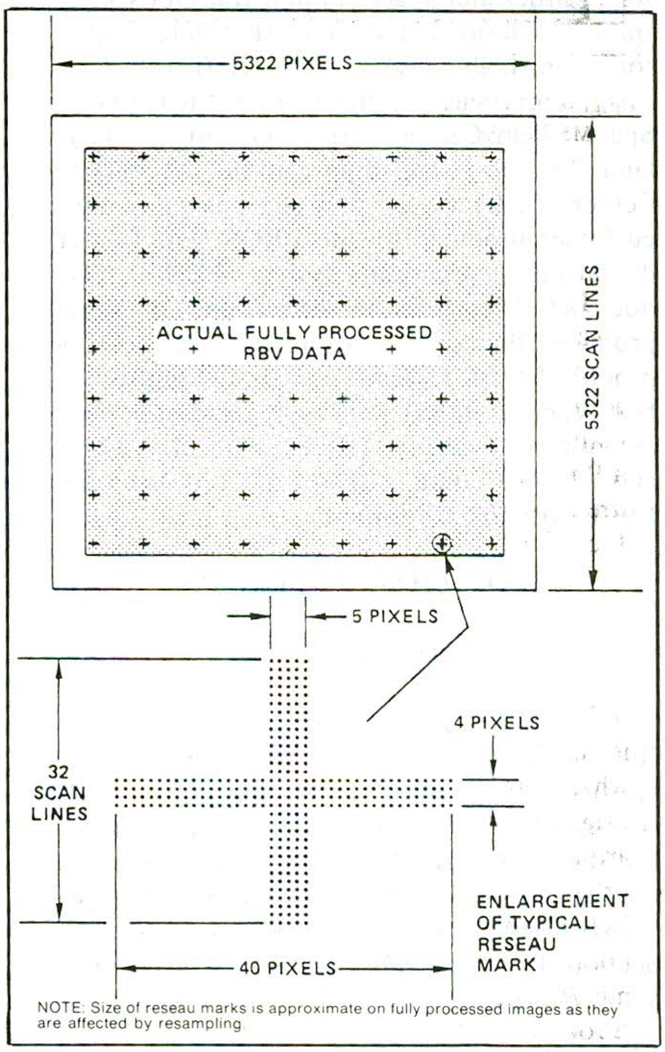


Figure 2.–Square data array of fully processed RBV imagery.

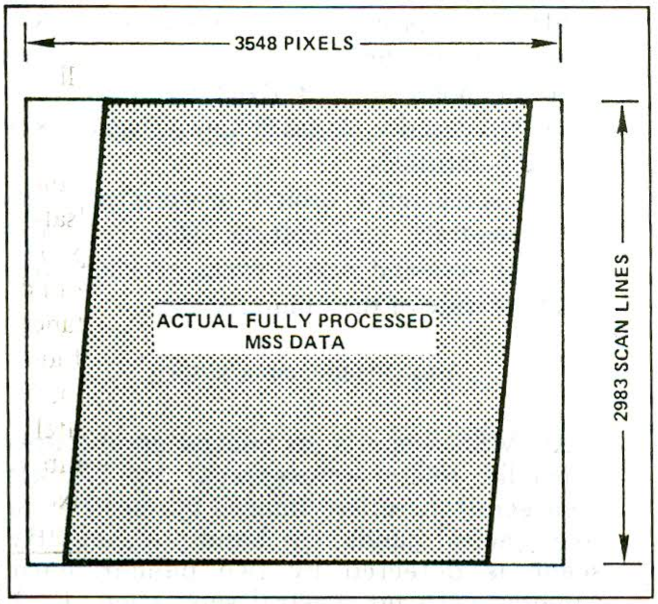


Figure 3.--Rectangular data array of fully processed MSS imagery.

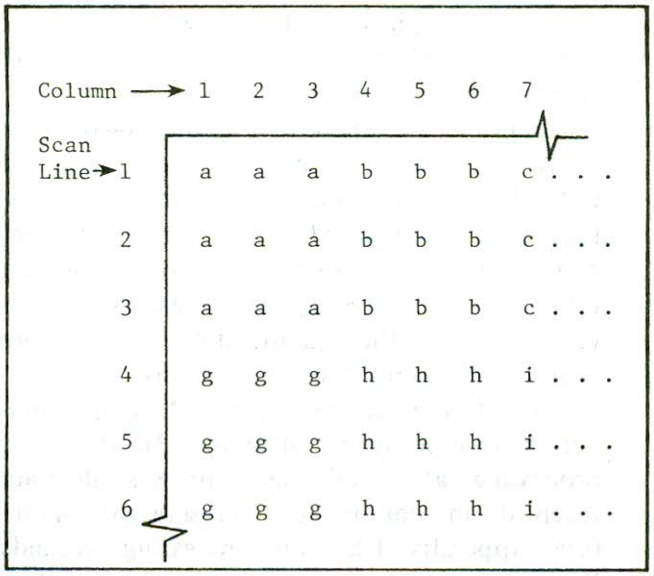


Figure 4.--Band 8 partially processed data replication.

DIRECTION OF SCAN

The scan mirror, or electron beam, operates in a scan-and-retrace cycle. The active scan is normal and right-to-left with respect to the satellite direction. The full cycle normally produces a 185 km sweep for MSS and a 99 km sweep for each RBV subscene. Figure 5 shows the composite scan pattern of the MSS.

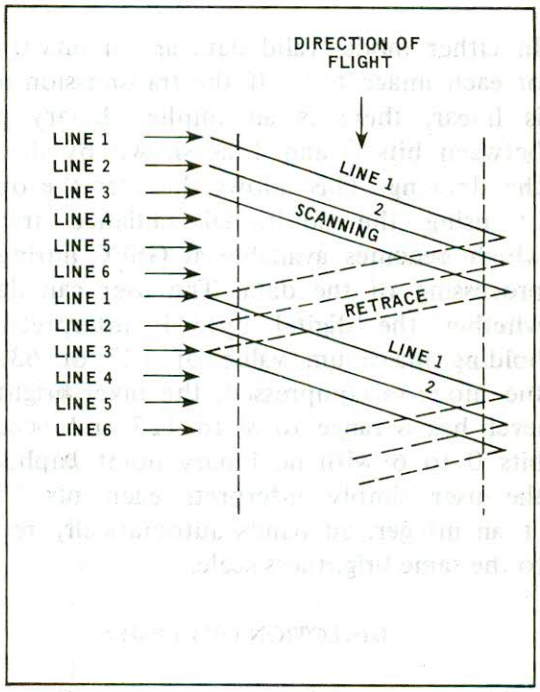


Figure 5.--Ground-scan pattern for three MSS detectors.

BRIGHTNESS VALUES

Each pixel is encoded in a byte. Each byte is composed of eight binary digits (bits), which are arranged to represent differing brightness values as binary numbers. As there are eight binary bits (each of which may be on or off), 256 values may be represented in each byte. However, not all of these values are possible. The satellite has two modes of transmission: linear and compressed. Bytes 3592 through 3596 of the header record identifies the transmission mode for each band.

Linear-transmission mode allows each pixel to have a brightness-value range of 0 to 63. RBV and MSS band 7 and band 8 data are transmitted in linear mode.

Compressed-transmission mode allows each pixel to have a brightness-value range of 0 to 127. MSS bands 4 through 6 are transmitted in compressed mode. These data are compressed to improve the signal-to-noise ratios. By compressing the high brightness-value signals, the quantization noise more nearly matches photomultiplier noise.

All data are received as six bit binary numbers (dynamic range of 0 to 63). However, processing at GSFC decompresses all data received in compressed transmission mode (see Appendix E). This processing expands the range of data to a dynamic range of 0 to 127 for decompressed data while linear data remains at a brightness range of 0 to 63.

All image data bytes on a CCT have seven bits of information:

0	X	X	X	X	X	X	X
7	6	5	4	3	2	1 ∧	0

In either mode, valid data are in bits 0 to 6 of each image byte. If the transmission mode is linear, there is an implied binary point between bits 0 and 1 as shown by the ∧ in the drawing. This allows the user the option of using the additional radiance fraction which becomes available at GSFC during the processing of the data. The user can decide whether the digital byte is interpreted as holding maximum value of 127 or 63.5 If the mode is compressed, the pixel brightness level has a range of 0 to 127 and occupies bits 0 to 6 with no binary point implied. If the user simply interprets each pixel byte as an integer, all bands automatically register to the same brightness scale.

DIRECTION OF FLIGHT

The spacecraft is in a near-polar orbit, which allows two periods of imaging. When the spacecraft travels north to south, it is in descending mode. Conversely, the ascending mode is a south to north direction. The transition points near the poles are not fixed terrestrial locations, but describe circles at approximately 82° N. and S. latitudes.

The spacecraft's orbital progress produces the along-track scan pattern, when combined with the scan-and-retrace cycle, provides complete coverage of the full image area.

DEFINITION OF A SCENE

An MSS scene is an imaged ground area normally 185km (cross-track) by 170 km (spacecraft direction) imaged by one, four, or five spectral bands. On Landsat-3, an RBV scene is detected by two panchromatic cameras with no spectral separation. Each RBV scene, normally 183 km by 181 km, is a composition of four RBV subscenes, with each subscene 99 km by 99 km.

UNCORRECTED AND CORRECTED DATA

CCT data can be requested as four separate products:

CCT-AM: partially processed MSS data (without geometric corrections applied).

CCT-PM : fully processed MSS data (with geometric corrections applied and resampled to a map projection).

CCT-AR : partially processed RBV data (without geometric corrections applied).

CCT-PR : fully processed RBV data (with geometric corrections applied and resampled to a map projection).

All four CCT products have been radiometrically corrected as discussed in Appendixes C and D.

A partially processed image is defined as one for which the correction data are provided as ancillary information, but which are not applied to the video data. An uncorrected scene has the systematic corrections and resampling transformations to two projections in the ancillary records on the CCT-AM for MSS and the

CCT-AR for RBV.

A fully processed CCT scene has systematic and geometric corrections applied and the data resampled to a specified projection. Such a scene is recorded on a CCT-PM (for MSS data) or CCT-PR (for RBV data).

Some of the systematic corrections include:

band-to-band offsets
line lengths
earth rotation (skew)
detector-to-detector sampling delay

A discussion of each of these major corrections is given in Appendix B. The other systematic corrections (pitch, yaw, altitude, use of ground control points, and so forth) are discussed in the *Landsat Data Users Handbook*. The exact method available to users to perform the geometric transformation contained in the ancillary information is given in Appendix A.

The differences between fully processed and partially processed image arrays are shown in figures 6 and 7. In addition, it should be noted that the actual image data are spatially corrected in the fully processed CCT. The dotted line on the right side of the partially corrected MSS array (fig. 6) indicates a varying line length. The correction transformation is applied in the corrected array and provided in the ancillary data for an uncorrected array.

PROJECTIONS AND RESAMPLING TECHNIQUES

In the process of geometrically correcting an image array, four different images can result because of the combinations of the two projections and two resampling techniques available.

Landsat data can be geometrically corrected to three map projections. The standard projection is Space Oblique Mercator (SOM). As an option, the data can be corrected to either Polar Stereographic (PS) or Universal Transverse Mercator (UTM). If the scene nadir is between 65° N. latitude and 65° S. latitude then the scene can be corrected to UTM. If the spacecraft nadir is outside of these bounds, then the alternative projection is PS. Appendix G provides information about these projections.

A CCT-AM or CCT-AR has the annotation records and transformation coordinates for both the standard SOM projection *and* the

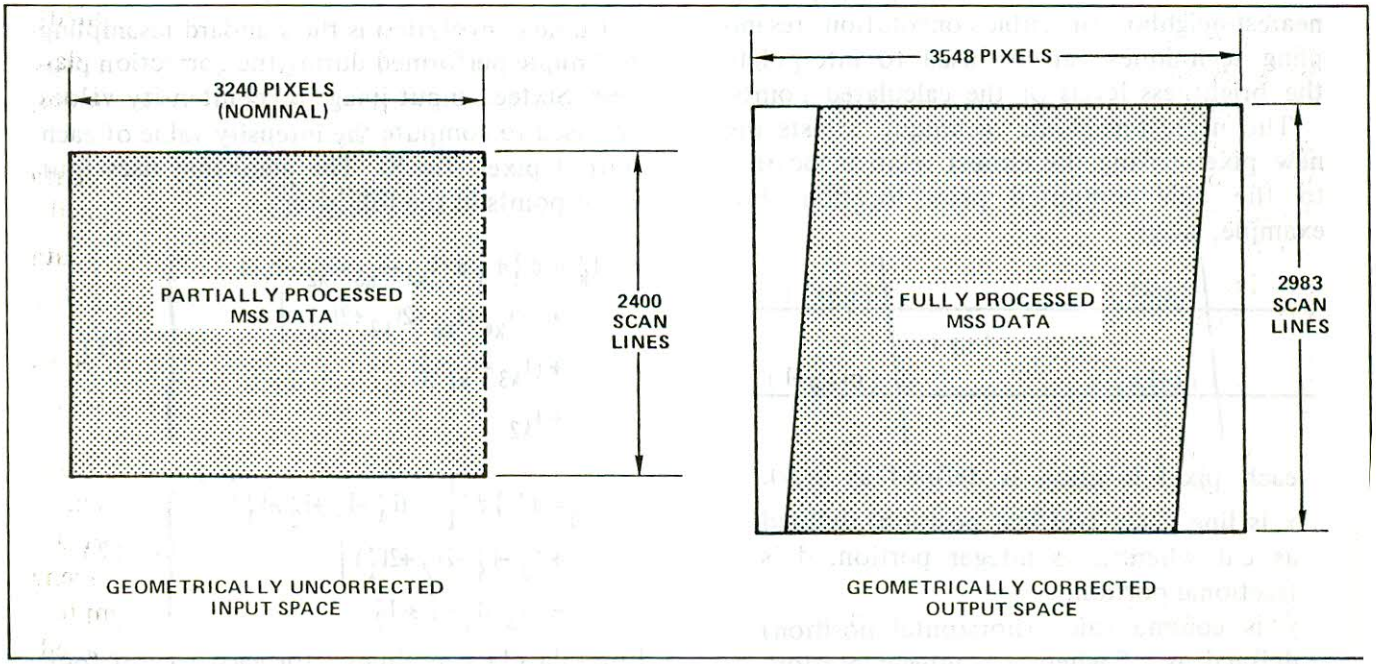


Figure 6.--An MSS scene.

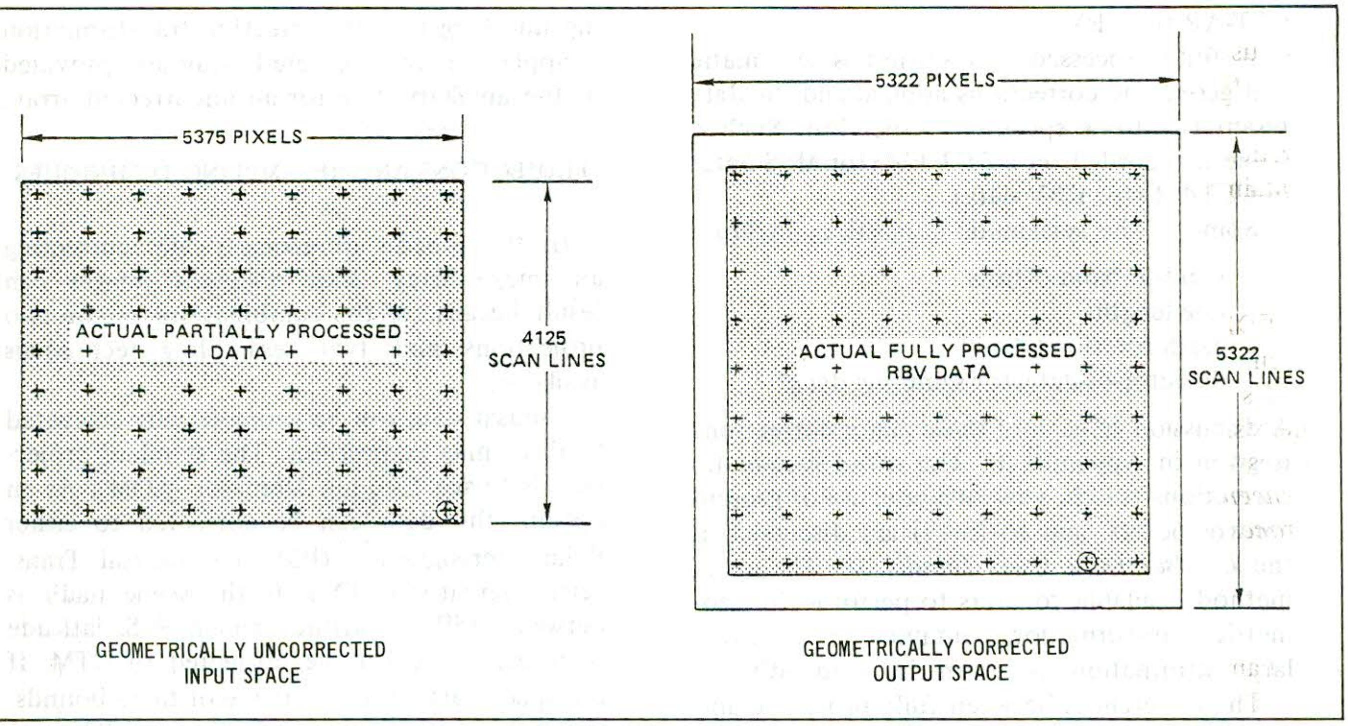
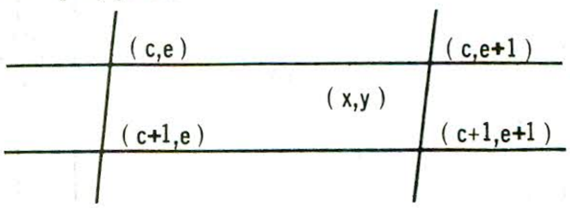


Figure 7.--An RBV scene.

optional UTM or PS projection. A CCT-PM or CCT-PR has the image data and annotation record for the SOM projection *or* the UTM or PS projection if requested.

When correcting image data points, either nearest-neighbor or cubic-convolution resampling techniques can be used to interpolate the brightness levels of the calculated points. The nearest-neighbor technique adjusts the new pixel having the closest relative location to the new computed pixel location. For example, given:



each pixel location is defined as (x,y).

x is line value (vertical position) defined as c.d where c is integer portion, d is fractional portion.

y is column value (horizontal position) defined as e.f where e is integer portion, f is fractional portion.

$$I(x,y) = I(c.d, e.f) = I(a,b)$$

$$\text{where } a = \begin{cases} c & \text{if } d < .5 \\ c+1 & \text{if } d \geq .5 \end{cases}$$

$$b = \begin{cases} e & \text{if } f < .5 \\ e+1 & \text{if } f \geq .5 \end{cases}$$

Cubic convolution is the standard resampling technique performed during the correction process. Sixteen input image-pixel-intensity values are used to compute the intensity value of each output pixel (fig. 8). The algorithm uses four input points in the following:

$$\left. \begin{aligned} I'_k = d\{d\,[&d(I_{k4} - I_{k3} + I_{k2} - I_{k1}) \\ &+ (-I_{k4} + I_{k3} - 2I_{k2} + 2I_{k1})] \\ &+ (I_{k3} - I_{k1})\} \\ &+ I_{k2} \end{aligned} \right\} \quad (1)$$

$$\left. \begin{aligned} I_{vu} = d'\{d'\,[&d'(I'_4 - I'_3 + I'_2 - I'_1) \\ &+ I'_3 - I'_4 - 2I'_2 + 2I'_1] \\ &+ (I'_3 - I'_1)\} + I'_2 \end{aligned} \right\} \quad (2)$$

Formula (1) is evaluated for each row of four points. The four input image brightness values

I_{k1}, I_{k2}, I_{k3}, I_{k4} and horizontal distance d are used to obtain an intermediate interpolated brightness value I_k. Then these four intermediate interpolated values I_1, I_2, I_3, I_4 and the vertical distance d are used in formula (2) to obtain the final brightness value I_{vu}.

ENHANCED DATA

EDIPS can provide certain enhancements to each image. A user may order a CCT product and specify any one of the following enhancements. The header record of each band indicates which options were performed. *Enhancements can only be provided with fully processed CCT's.*

CONTRAST ENHANCEMENT

Landsat data usually occupy a small subset of the total brightness range. To provide optimal contrast and color variation when color compositing, a linear contrast stretch may be performed on the image data.

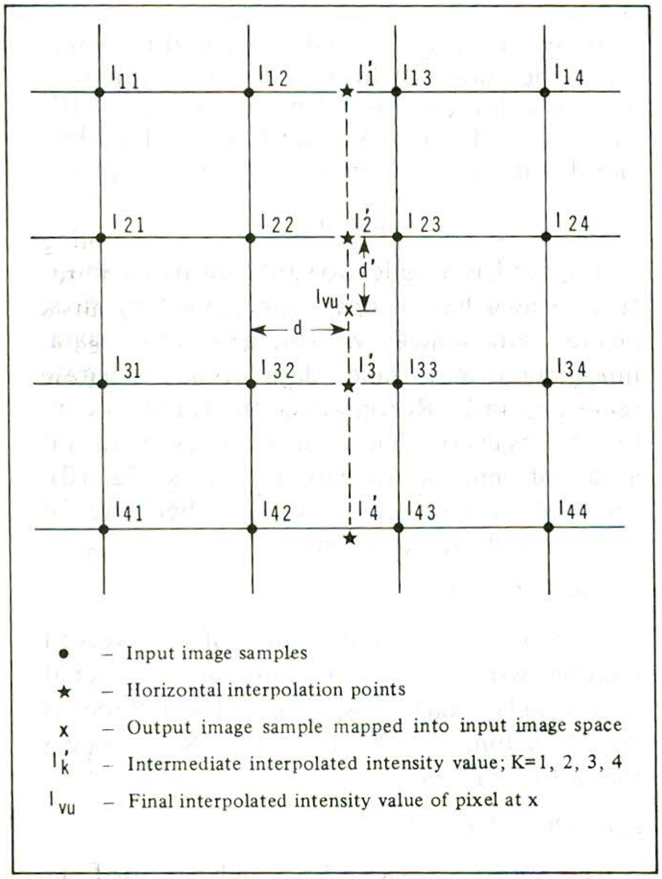


Figure 8.--Cubic convolution.

The contrast-enhancement algorithm is either an automatic or parametric linear stretch of minimum-maximum brightness levels defined by:

$$\text{OUTPUT} = \left[\frac{\text{INPUT-MINIMUM}}{\text{maximum-minimum}}\right] \bullet 127$$

where output values less than the lower threshold are set to zero and any values above the upper threshold are set to 127. The minimum and maximum values may be obtained by an algorithm either automatically based on brightness-value distribution or specified by the user at the time of the order. These values may be specified in either gray-level values or percents. If contrast enhancement is performed, the maximum and minimum values used for each band or subscene will be given in their respective trailer records.

ATMOSPHERIC SCATTER COMPENSATION

The algorithm for atmospheric scatter compensation performs a simple bias on each pixel value:

$$\text{OUTPUT} = \text{INPUT} - \text{BIAS}$$

The bias may be specified at the time of the order to remove the effects of atmospheric contaminants. If the compensation is performed on the image data, the actual bias value used is given in the trailer record of each band.

EDGE ENHANCEMENT

Edge enhancement is a technique to "sharpen" the Landsat image by enhancing the high-frequency image components. This is done by exaggerating the difference between the pixel and the N x M neighborhood (kernel) immediately surrounding it. The kernel size (N, M) is specified at the time of order with N, M as 1, 3, 5, 7, or 9. The kernel does not have to be square or the same for each band or subscene; but N and M must be odd valued integers. The local average is computed as follows:

SV(I+1, J) : = SV(I, J) – T(I+1, J) + B(I+1, J)

SH(I, J+1) : = SH(I, J) + SV(I, J+N) – SV(I, J)

X1 (I, J) : = SH(I, J) / (N*M), I, J = 1, 2, 3 . .

where

SV(I, J) is the sum of the pixel values inside the kernel box along the vertical axis.

SH(I, J) is the sum of the SV(I, J) values inside the kernel box along the horizontal axis.

T(I, J) is the scan line uncovered by advancing the filter to line I.

B(I, J) is the scan line covered by advancing the filter to line I.

After computing the local average X1(I, J), the output (enhanced) pixel value Y(I, J) is given by:

Y(I, J) : = X(I, J) + X(I, J) – X1(I, J)

If edge enhancement is performed on the video data, the kernel size employed is given in the trailer record of each band.

TAPE FORMAT

GENERAL

The CCT's produced by EDIPS are classified by two major data distinctions: sensor type (MSS or RBV), and whether or not geometric corrections have been applied to the image data. Four types of CCT's result:

CCT-AM: partially processed MSS data (with geometric corrections applied).

CCT-PM: fully processed MSS data (with geometric corrections applied and resampled to a map projection).

CCT-AR: partially processed RBV data (without geometric correcitons applied).

CCT-PR: fully processed RBV data (with geometric corrections applied and resampled to a map projection).

These CCT's can be produced in either a band interleaved by line (BIL) or a band sequential (BSQ) format and in either 800 bpi or 1600 bpi densities. RBV data is produced on a per subscene basis which is equivalent to BSQ with only one band. While each of these CCT's may require varying numbers of records and tape reels, a general data format that applies to all CCT's is shown in figure 9.

CONVENTIONS

BYTE

A byte is eight bits in length and may contain character or numeric data. The most significant bit occurs first and is the left-most bit of the byte.

IMAGE DATA

Image data will be right-justified in a byte with the most significant bit zero filled. A binary value of zero is low radiance for RBV and bands 4 through 7, and "cold" for MSS band 8 data. Each image datum is a pixel.

RECORD

A record is a collection of data items and is treated as a logical unit. Tape directory data, header data, ancillary data, annotation data, image data, and trailer data occupy separate sets of records. Records are structured to contain six bytes of identification codes, data, and a variable number of zero fill bytes (fig. 10). The first six bytes are: record number, zero fill byte, and record type code.

RECORD NUMBER

This is a sequential count of the record number within a file. Records are numbered sequentially, starting with one. The number is coded in binary, with the left-most bit being the most significant.

ZERO FILL BYTE

This byte is binary-zero filled and used for data alignment.

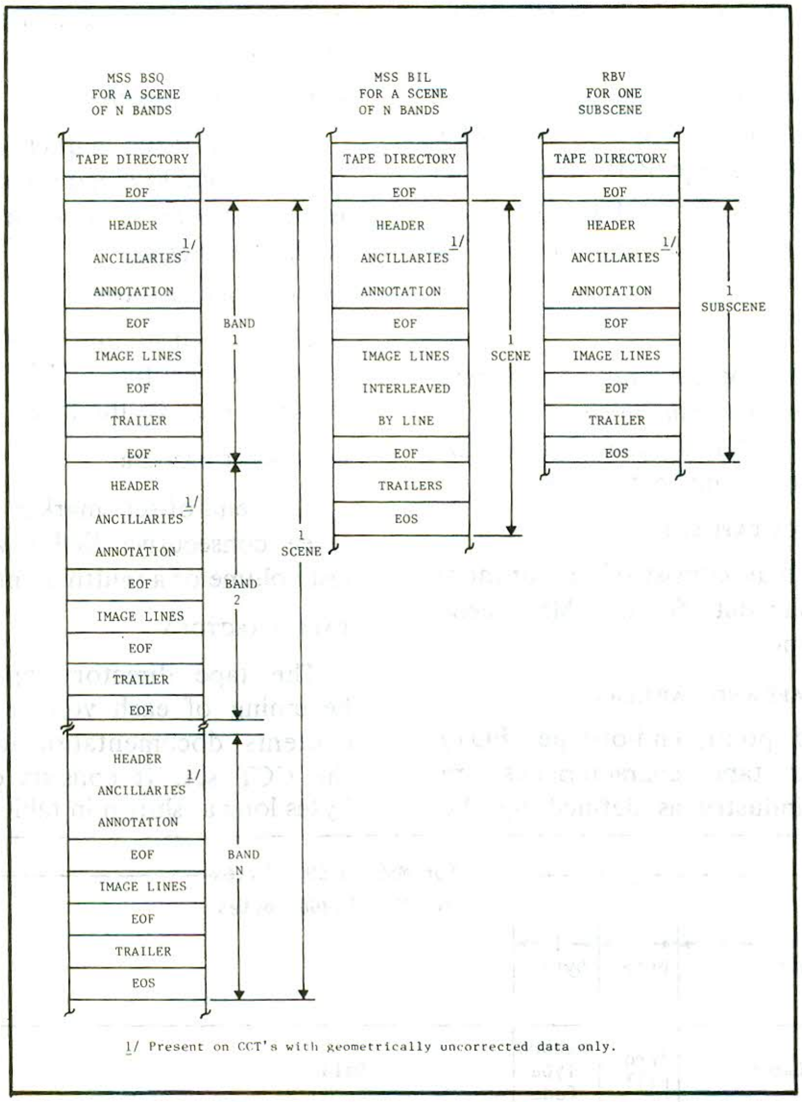


Figure 9.–Data format of EDIPS CCT's.

RECORD TYPE CODE

Each record contains one of six types of information, uniquely identified by the record type code. The record type codes are binary numbers with the following octal values:

Tape directory	011_8
Header	022_8
Ancillary	044_8
Annotation	333_8
Image	355_8
Trailer	366_8

FILE

A file is a collection of related records treated as a unit. The amount of data contained in a file depends on sensor type (MSS or RBV), the interleaving of image data, and whether or not the data are geometrically corrected. A CCT contains four types of files:

- Tape-directory data
- Scene-attributes data
- Image data
- Trailer data

Each file can contain one or more records as defined below. The total number of files on the CCT depends on the format: BSQ or BIL (fig. 9). The length of records within each file is fixed and blocked one (1). The tape directory file has a fixed length on all CCT tapes and gives the lengths of records in all subsequent files.

Only an image-data file may be split between reels of CCT's. It should be noted that one RBV image data file contains one RBV subscene of imagery. One MSS image file contains either one image (band) in BSQ or one scene in BIL (fig. 9).

VOLUME

A volume is one physical unit of a storage medium on which data can be recorded and subsequently read. In this document, a volume always refers to a reel of magnetic tape.

CCT TAPE SET

A CCT tape set may consist of one or more volumes and contain data for one MSS scene or one RBV subscene.

TAPE GAPS AND MARKERS

Tape gaps, load point, end-of-tape (EOT) marks, and other tape characteristics are standard for the industry as defined by the American National Standards Institute (ANSI, 1973a and b).

END-OF-FILE MARKER

The end-of-file marker (EOF) is a specifically coded block which separates files. The EOF is the tape mark described in the referenced ANSI documents.

END-OF-VOLUME MARKER

The end-of-volume (EOV) indicator consists of two consecutive EOF's and marks the end of recorded data on the tape.

END-OF-SET MARKER

The end-of-set marker (EOS) consists of three consecutive EOF's and occurs on the last volume of a multivolume set.

TAPE DIRECTORY

The tape directory appears once at the beginning of each volume and identifies the contents, documentation level, and format of the CCT set. It consists of one record 360 bytes long as shown in table 1.

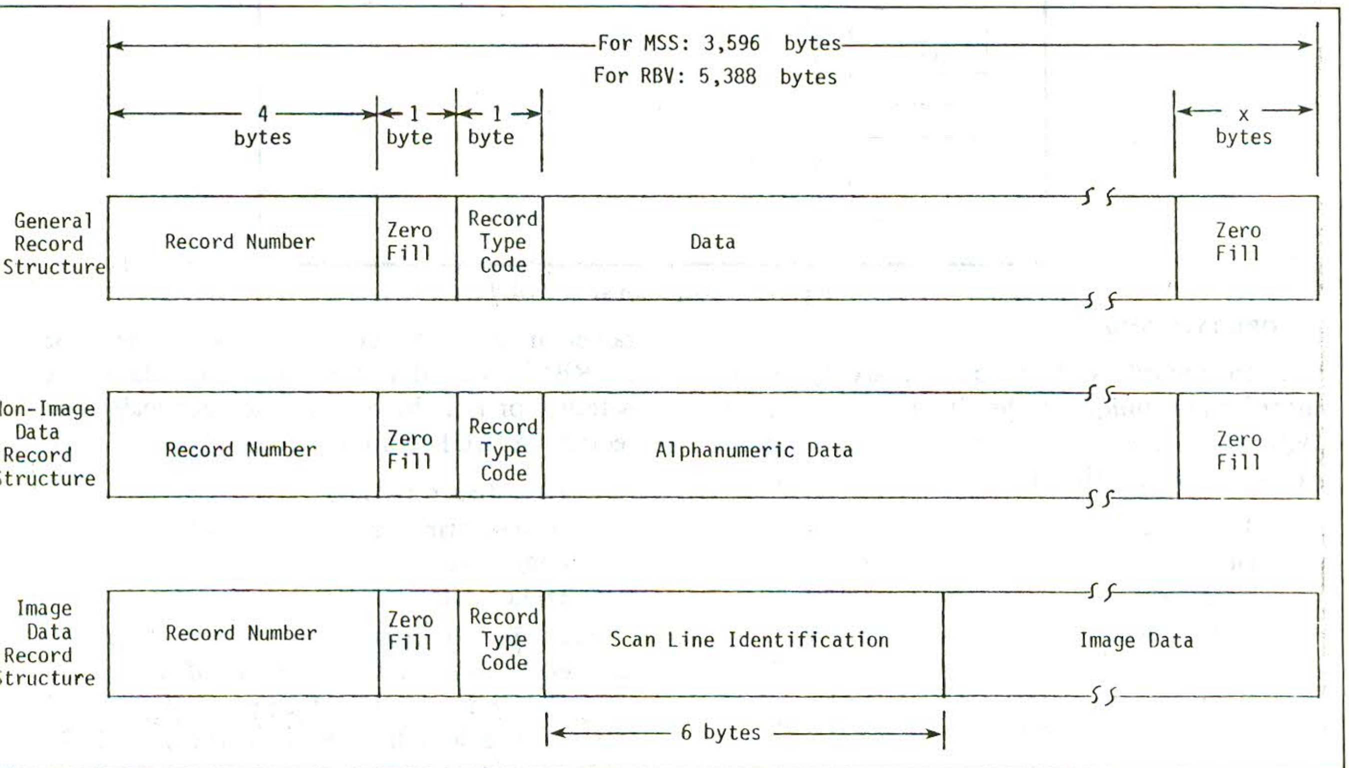


Figure 10.–Standard CCT record structure.

TABLE 1.--Tape directory: Record-byte assignments

BYTES	DATA	DESCRIPTION
1-4	XXX XXX XXX XXX	Record Number--always a binary 1
5	000	Zero Fill
6	011_8	Record Type Code
7-26	L N S T T Y Y D D D X X N V b̸ b̸ b̸ b̸ b̸ b̸	Tape ID - 20 ASCII bytes of tape identification coded: L = Mission Designator, coded L for Landsat N = Mission Number, coded: 1, 2, or 3 S = Sensor Type, coded: M (MSS) or R (RBV) TT = Tape Type, coded: CP (Data with geometric corrections), or CA (Data without geometric corrections) Date of Tape YY = Last two digits of year Creation: DDD = Julian Day XX = Sequence number within day for each tape type N = CCT Volume Number V = Number of volumes in CCT set b̸ = Blanks
27-29	Day Mon Yr	Date of CCT Tape Generation - will contain the date in binary (Yr = last two digits of year)
30	XXX	Site of CCT Production: 011_8 = IPF (MDP#1) at GSFC 022_8 = IPF (MDP#2) at GSFC) 044_8 = IPF (QLP) at GSFC 355_8 = EDIPS at EDC (This manual only describes CCT's generated by EDIPS)
31	I	Interleaving Type Indicator, with I = 000_8 for MSS BSQ and RBV; or 377_8 for MSS BIL
32-33	XXX XXX	Record length in bytes of records to follow given in binary either 3596_{10} for MSS or 5388_{10} for RBV

TABLE 1.--(cont'd)

BYTES	DATA		DESCRIPTION
34		H	Source HDT - one ASCII byte where: If H = C, the source HDT contains geometrically corrected data If H = U, the source HDT contains geometrically uncorrected data If H = b̸, field is N/A
35-52	A	D	Scene Identification - an 18 byte ASCII field giving Scene ID and WRS Designator of the data on the tape (or tape set) defined as follows -
	D	D	
	D	H	Scene ID - unique scene identifier of the form:
	H	M	ADDDDHHMMSB where
	M	S	A = Landsat mission = 1, 2, or 3 DDDD = Day number, relative to launch, at time of observation
	B	M	HH = Hour at time of observation
	P	P	MM = Minute at time of observation S = Tens of seconds at time of observation
	P	R	B = Blank
	R	R	WRS Designator - unique terrestrial scene of the form: MPPPRRR where M = A (for ascending node) or D (for descending node) PPP = nominal WRS path number (001-251) RRR = nominal WRS row number (001-248)
53-358	000	000	Zero Fill
359-360	SSS	LLL	Version level on the CCT set. SSS--Binary version number of the software. (Changes each release of module which generates CCT's.) LLL--Binary version number of the document which describes the CCT format. V.R (Changes each version of the CCT document. Revision changes have no impact.)

SCENE ATTRIBUTES FILE

The scene attributes file can contain up to three types of records: header, ancillary, and annotation. The total number of records in the file depends on the sensor and whether or not the data are geometrically corrected. The attributes file contains records of descriptive information concerning the image within the image file. A CCT in BSQ format contains one attributes file that contains the header, ancillary (if present) and annotation records for the bands on the CCT set. The header record is the first record of each attributes file, followed by all the ancillary (if present), and then the annotation records. For both BIL and BSQ formats, the relative order as given below is important.

HEADER RECORDS

A header record is present for each band on a BSQ CCT set and only once in a BIL CCT set. It identifies the contents of the data that follow and describes the format in which the data are recorded. Header data are further subdivided into six groups:

a) Scene identification	– bytes 1-36
b) Spacecraft description	– bytes 37-62
c) Time of exposure and WRS information	– bytes 63-92
d) Data set characteristics	
1) Header data	– bytes 93-98
2) Annotation	– bytes 99-102
3) Ancillary data	– bytes 103-110
4) Image data	– bytes 111-141
5) Trailer data	– bytes 142-150
e) Special purpose fields	– bytes 151-236
f) EDIPS processing information	
for MSS	– bytes 3583-3596
for RBV	– bytes 5375-5377

Table 2 shows the layout of header records, and table 2a the active detector-status bytes.

TABLE 2.--Header record: Record-byte assignments

Bytes	Data		Description
1-4	XXX	XXX	Record number Always a binary 1 for each file present.
	XXX	XXX	
5	000		Zero fill
6		022	Record Type Code
7-8	ƀ	A	Image ID - unique image identifier (in ASCII) of the form:
9-10	D	D	ADDDDHHMMSB where
11-12	D	D	ƀ = blank
13-14	H	H	A = Landsat mission = 1, 2, or 3 DDDD = Day number, relative to launch, at time of observation
15-16	M	M	HH = Hour at time of observation
17-18	S	B	MM = Minute at time of observation S = Tens of seconds at time of observation B = IPF ID code = 1, 2, 3, A, B, C, or D indicating RBV; 4, 5, 6, 7, 8, or 0 (if BIL) indicating MSS

TABLE 2.--(cont'd)

Byte	Data		Description
19-20	b̸	M	WRS designator - unique terrestrial image identifier (in ASCII) of the form: MPPPRRR where M = A (for ascending node) or D (for descending node); PPP = Nominal WRS path number (001-251); RRR = Nominal WRS row number (001-248)
21-22	P	P	
23-24	P	R	
25-26	R	R	
27-28	Day	Mon	Date of tape generation - will contain the date in binary. (Last 2 digits of Yr.)
29	Yr		
30		000	Not used (zeros)
31-36	000	000	
B. Spacecraft Description			
37-38	X	X	Sensor ID - the sensor will always be either MSS or RBV. The ID will be in ASCII.
39-40	X	b̸	
41-44	b̸	b̸	
45-46	000	00x	Mission number - will be either a binary 1, 2, or 3 depending on the spacecraft.
47-48	XXX	XXX	Orbit number - binary number reflecting the orbit number of the spacecraft.
49-56 . . . . For MSS:			
49-50	XXX	XXX	Active detector status - contains detector status for the 26 MSS detectors. There is 1 bit per detector starting left to right with 1 indicating an active status. If a sensor is disabled during the data acquisition pass, this status will reflect inactive (0) for the disabled detector. See table 2-a for details.
51-52	XXX	XXX	
53-54	000	000	
55-56	000	000	
49-56 . . . . For RBV:			
49-50	000	000	Active camera status - contains camera status for up to 3 RBV cameras. There is 1 bit per

TABLE 2.--(cont'd)

Bytes	Data		Description
51-52	000	00X	camera as shown below. A bit set to 1 indicates an activated camera. (If a camera is disabled during the data acquisition pass, this status will be shown as a 0 for the disabled camera.)
53-56	000	000	
			Byte 52: 0 0 0 0 0 J K L
			where bits J, K, and L represent cameras 1, 2, and 3 respectively.
57	XXX		Active detector/camera count - a binary value representing the number of active detectors/cameras based on the active detector/camera status
58-59	XXX	XXX	Nominal number (in binary) of pixels/scan line in original geometrically uncorrected image
60-62	000	000	Not used (zeros)
C. Time of Exposure/WRS Designator			
63-72	000	000	Not used (zeros)
73-74	XXXXXX		WRS designator in fully processed image (in binary): scan line number of WRS
75-76	XXXXXX		Pixel number of WRS
			Center picture exposure time (in ASCII):
77-78	Yr	Yr	Last 2 digits of year (00-99)
79-80	D	D	Julian day of year (3 digits: 001-366)
81-82	D	Hr	Hour (2 digits: 00-99)
83-84	Hr	Min	Minutes (2 digits: 00-59)
85-86	Min	Sec	Seconds (2 digits: 00-59)
87-88	Sec	ms	Milliseconds (3 digits: 000-999)
89-90	ms	ms	ƀ = blank
91-92	ƀ	ƀ	

TABLE 2.--(cont'd)

Bytes	Data	Description
D. Data Identification and Characteristics		
93-94	XXX XXX	Header record length - either 3596_{10} for MSS or 5388_{10} for RBV
95-96	XXX XXX	Number of header records - nominally 1
97-98	XXX XXX	Number of bytes of header data
Annotation Data Characteristics		
99-100	XXX XXX	Annotation record length - either 3596_{10} for MSS or 5388_{10} for RBV
101-102	XXX XXX	Number of annotation records - 1 if data are geometrically corrected, 2 if uncorrected
Ancillary Data Characteristics		
103-104	XXX XXX	Ancillary record length - either 3596_{10} for MSS or 5388_{10} for RBV
105-106	XXX XXX	Number of ancillary records - 0 if data are geometrically corrected, 26_{10} if MSS uncorrected, 30_{10} if RBV uncorrected
107	XXX	Geometric corrections applied - either 000_8 (no) or 377_8 (yes)
108	XXX	Geometric correction data present - either 000_8 (no) or 377_8 (yes)
109	XXX	Radiometric correction applied - either 000_8 (no) or 377_8 (yes)
110	XXX	Radiometric correction data present - either 000_8 (no) or 377_8 (yes)
Image Data Characteristics		
111-112	XXX XXX	Image record length - either 3596_{10} for MSS or 5388_{10} for RBV
113-114	000 000	Not used (zeros)
115-116	XXX XXX	Number of calibration/quality data words per scan line

TABLE 2.--(cont'd)

Bytes	Data	Description
117	XXX	Image data format = 000_8 for unframed rectangular image, 377_8 for framed rectangular image, 366_8 for framed square image
118-119	000 000	Not used (zeros)
120	XXX	Interleaving type indicator - either 000_8 for BSQ or 377_8 for BIL
121	XXX	BIL line interleaving count - 5_{10} if Landsat-3, 4_{10} if Landsat-1 or -2, 0 for N/A
122	008	Number of bits per pixel - for this application it will be constant 8_{10}
123	XXX	Resampling applied: 300_8 = None, 011_8 = Cubic convolution, or 022_8 = Nearest neighbor
124	XXX	Map projection applied (corresponds to first map projection in ancillary and annotation data sections): 300_8 = None, 011_8 = Universal Transverse Mercator, or 022_8 = Polar Stereographic
125-126 . . . . For MSS		
125-126	XXX XXX	WRS offset from fully processed image center - right (positive) left (negative) pixel displacement of the World Reference System designation with respect to the picture center pixel (scan line 1492, pixel 1774). (Most significant bit indicates the sign; "0" = positive with WRS to right of picture center and "1" = negative with WRS left of picture center.) For image data without geometric corrections, zeros
125-126 . . . . For RBV		
125-126	000 000	Not used (zeros)
127-128	000 000	Not used (zeros)

TABLE 2.--(cont'd)

Bytes	Data	Description
129	XXX	Image data justification - 0_8 indicates left justification, 377_8 indicates right justification, for this application: 377_8
130	XXX	Location of most significant bit - 0_8 indicates left, 377_8 indicates right, for this application: 0_8
131-132	XXX XXX	Number of pixels per scan line
133-134	000 000	Not used (zeros)
135	XXX	Number usable images (or subscenes) per scene - this will contain either 1_{10}, 4_{10}, or 5_{10}
136	XXX	MSS band number (in ASCII): 4, 5, 6, 7, 8, or 0 (indicating BIL) or RBV camera number (in ASCII); A, C - camera 1; B, D - camera 2
137-139	000 000	Not used (zeros)
140-141	XXX XXX	Number of bits of support data or "one" filler in the end of each image data record: PM - 252_{10} PR - 378_{10} AM - 252_{10} AR - 7_{10}
	Trailer Data Characteristics	
142-143	XXX XXX	Trailer record length - either 3596_{10} for MSS or 5388_{10} for RBV
144-145	XXX XXX	Number of trailer records - nominally one per image
146-150	000 000	Zero filler
E.	Special Purpose Fields	
151	XXX	Day/night flag - if 000_8 = day pass 377_8 = night pass
152-161	000 000	Not used (zeros)

TABLE 2.--(cont'd)

Bytes	Data	Description
	162 . . . . For MSS	
162	XXX	Cal wedge mode 007_8 = low gain linear transmission 070_8 = low gain compressed transmission 077_8 = high gain linear transmission 300_8 = high gain compressed transmission
	162 . . . . For RBV	
162	000	Not used (zeros)
	163-214 . . . . For Imagery with Geometric Corrections	
		Temporal Registration Data:
163-164	b̸ | A	Scene ID (20 ASCII bytes) of referenced scene used for temporal registration processing of the form:
165-166	D | D	
167-168	D | D	ADDDDHHMMSB where
169-170	H | H	A = Landsat mission - 1, 2, or 3
171-172	M | M	DDDD = Day number, relative to launch, at time of observation
173-174	S | B	HH = Hour at time of observation MM = Minute at time of observation S = Tens of seconds at time of observation B = IPF ID code = (RBV) 1, 2, 3, A, B, C, or D; (MSS) 4, 5, 6, 7, or 8
175-176	b̸ | M	WRS designator - unique terrestrial image identifier (in ASCII) of the form:
177-178	P | P	
179-180	P | R	MPPPRRR where
181-182	R | R	M = A (for ascending node) or D (for descending node) PPP = nominal WRS path number (001-251) RRR = nominal WRS row number (001-248)
183-214	XXX | XXX	Scan line and pixel numbers for temporal registration marks for referenced image and current image (image under processing). Temporal registration points P_1 through P_4 are given in the following tabular form. Entries denote byte assignments for binary scan line numbers and pixel numbers.

TABLE 2.--(cont'd)

Bytes	Data	Description

Temporal Registration Point	CURRENT IMAGE Scan Line Number	CURRENT IMAGE Pixel Number	REFERENCE IMAGE Scan Line Number	REFERENCE IMAGE Pixel Number
P_1	177 - 178	179 - 180	181 - 182	183 - 184
P_2	185 - 186	187 - 188	189 - 190	191 - 192
P_3	193 - 194	195 - 196	197 - 198	199 - 200
P_4	201 - 202	203 - 204	205 - 206	207 - 208

163 - 214 . . . . For Imagery without Geometric Corrections:

Bytes	Data	Description
163-214	000 000	Not used (zeros)

215 - 230 . . . . For MSS Imagery with Geometric Corrections:

Overlap Data:

Scan line & pixel numbers (in binary) of the four overlap marks:

Bytes	Data	Description
215-216	XXX XXX	Scan line of first overlap mark (upper left)
217-218	XXX XXX	Pixel number of first overlap mark
219-220	XXX XXX	Scan line of second overlap mark (upper right)
221-222	XXX XXX	Pixel number of second overlap mark
223-224	XXX XXX	Scan line of third overlap mark (lower left)
225-226	XXX XXX	Pixel number of third overlap mark
227-228	XXX XXX	Scan line of fourth overlap mark (lower right)
229-230	XXX XXX	Pixel number of fourth overlap mark

215 - 230 . . . . For MSS imagery without geometric corrections and RBV imagery:

Bytes	Data	Description
215-230	000 000	Not used (zeros)

231 . . . . For MSS:

Bytes	Data	Description
231	XXX	Nominal overlap mark pixel offset (in binary)

Table 2.--(cont'd)

Bytes	Data	Description
	231	For RBV:
231	000	Not used (zeros)
232	XXX	Quality assessment (in ASCII) of applied geometric modeling. Coded as 9 for highest to 0 for lowest. The assessment is based on the number of control points applied by setting the code equal to the truncated integer value of the expression $\frac{N+7}{8}$ where N is the number of control points.
	233-236	For MSS imagery with geometric correction applied:
233-236	T | L R | B	Actual number of tick marks (in binary for Top (T), Left (L), Right (R), and Bottom (B) annotation zones.
	233-236	For RBV and MSS imagery without geometric corrections:
233-236	000 000 000 000	Not used (zeros)
	237-560	For MSS:
237-560	000 000 ⋮ 000 000	Not used (zeros)
	237-560	For RBV:
237-560	XXX XXX ⋮ XXX XXX	Computed Reseau Pattern locations in the fully processed image (if CCT-AR then of first projection) - starting at the upper left corner, left to right and top to bottom. The center of each Reseau location is provided in four bytes (2 bytes for binary scan line and 2 bytes for binary pixel location). If the Reseau is not located, a default 0,0 is entered.

Table 2.--(cont'd)

Bytes	Data	Description
237-560		For MSS
237-560	XXX XXX : XXX XXX	Not used (zeros)
560-3582 (MSS) or 560-5374(RBV)	000 000 000 000	Not used (zeros)
3583 (MSS) or 5375 (RBV)	XXX	EDIPS performed contrast enhancement (False - 0_8 True - 377_8)
3584 (MSS) or 5376 (RBV	XXX	EDIPS performed atmospheric scatter compensation (False - 0_8 True - 377_8)
3585 (MSS) or 5377 (RBV)	XXX	EDIPS performed edge enhancement (False - 0_8 True - 377_8)
3586-3596		For MSS BIL only
3586	XXX	Indication of data present by band - actual data is indicated as present by a 1 in the proper bit position. Positions for placement of the 1 for bands 4 through 8 is as follows: 00045678 When data for a given band is not present, it's position will contain a zero rather than a 1.

Table 2.--(cont'd)

Bytes	Data	Description
3587	G(4) G(5) G(6) G(7) G(8)	A five-byte field, with one byte for each of MSS bands 4, 5, 6, 7, and 8 to indicate sensor gain options, ASCII coded: G = "H", high gain G = "L", low gain
3592-3596	T(4) T(5) T(6) T(7) T(8)	A five-byte field with one byte for each of MSS bands 4, 5, 6, 7, and 8 to indicate the type of MSS transmission, ASCII coded: T = "1", linear mode T = "2", compressed mode

TABLE 2-a.--Active-detector-status bytes

Bit Position in Bytes 49-52	Intra-Band Detector Assignment
1	Band 4 Detector 1
2	Band 4 Detector 2
3	Band 4 Detector 3
4	Band 4 Detector 4
5	Band 4 Detector 5
6	Band 4 Detector 6
7	Band 5 Detector 1
8	Band 5 Detector 2
9	Band 5 Detector 3
10	Band 5 Detector 4
11	Band 5 Detector 5
12	Band 5 Detector 6
13	Band 6 Detector 1
14	Band 6 Detector 2
15	Band 6 Detector 3
16	Band 6 Detector 4
17	Band 6 Detector 5
18	Band 6 Detector 6
19	Band 7 Detector 1
20	Band 7 Detector 2
21	Band 7 Detector 3
22	Band 7 Detector 4
23	Band 7 Detector 5
24	Band 7 Detector 6
25	Band 8 Detector A
26	Band 8 Detector B
27 - 32	Not Used (Zero)

ANCILLARY RECORDS

The ancillary records occur only on CCT's that are geometrically uncorrected (CCT-AM or CCT-AR). The number of records depends on the sensor. The ancillary records contain various kinds of correction data that the user can apply to the image data to produce a geometrically correct image. For each band or subscene, the ancillary information for two projections is provided (SOM and either PS or UTM).

The contents of the ancillary records can be divided into two areas: geometric-modeling data and projection-dependent data. The first two records of ancillary data contain the modeling data.

MODELING DATA. The modeling information of the ancillary data shown in table 3 provides characteristics of the corrected image array and satellite. The numerical data is in one of three formats: fixed point binary or floating point binary, or single precision floating point binary.

SIGN	INTEGER
Bit 0 + = 0 – = 1	Bits 1 through 31

Fixed Point Binary (FB)

where bit 0 is the most significant bit

SIGN	CHARACTERISTICS	FRACTION	
		FL	FLS
Bit 0 + = 0 - = 1	Bits 1 thru 7 Range -64 through +63. Treated as excess 64. Characteristic indicates the power.	Bits 8 thru 63 14 hexadecimal digits Fraction multiplied by power of 16 Long precision (doubleword) format	Bits 8 thru 31 6 hexadecimal digits Fraction multiplied by power of 16 Long precision (doubleword) format

Floating Point Binary (FL) and

Single Precision Floating Point Binary (FLS)

PROJECTION DEPENDENT DATA. The remaining ancillary records are the projection dependent data. Header byte 124 indicates which additional projection besides SOM is included: PS or UTM. For MSS data, 8 records each provide projection correction to two of the three projections. For RBV data, the modeling data are followed by 14 records for each of the two projections. All horizontal-row (HRS) and vertical-row (VRS) coordinates are given in four byte signed values as:

SIGN	INTEGER	FRACTION
1 bit	13 bits	18 bit

binary point

+ = 0
– = 1

Tables 4 and 5 show the layouts of the projection dependent data for MSS and RBV, respectively. In summary, the ancillary records on a CCT-AM are 2 modeling, 8 UTM or PS, 8 SOM, and 8 records of zero fill. A CCT-AR contains 2 modeling, 14 UTM or PS, and 14 SOM records. The correct application of the ancillary projection data is discussed in Appendix A.

TABLE 3.--Modeling data records: Record-byte assignments

BYTES Record 1	ENCODED 1/	DESCRIPTION
1-4	FP	Record Number
5	000_8	Zero Fill
6	044_8	Record Type Code
7-10	FP	Nominal number of pixels per input line
11-14	FP	Number of input lines in the partially processed image
15-22	FL	Nominal scale of input inter-pixel distance in meters per pixel
23-30	FL	Nominal scale of input inter-line distance in meters per pixel

1/ See text under modeling data.

Table 3.--(cont'd)

BYTES Record 2	ENCODED	DESCRIPTION
For MSS		
103-110	FL	Input image line coordinate of nadir in partially-processed output
111-118	FL	Input image pixel coordinate of nadir in partially-processed output
119-126	FL	If MSS, normalize spacecraft velocity at nadir.
127-134	FL	If MSS, Earth rotation velocity at nadir in meters per second.
135-138	FLS	If MSS, the Earth rotation parameter (image skew), α_{eR}, in radians
139-250	FL	Attitude/altitude coefficients (14 values) (8 bytes each)
251-264	FP	Number of GCPS in altitude/attitude fit
265-3596	FP	Zero fill
For RBV		
103-118	FP	Zero fill
119-119	ASCII	RBV image identification (A,B,C, or D)
120-142	FP	Zero fill
143-166	FL	Attitude coefficients (3 values)
167-174	FL	Measured spacecraft altitude (KM) at time of image exposure. (If MSS altitude is used, this parameter is taken from MSS data.)
175-250	FP	Zero fill
251-254	FP	Number of GCP's used in attitude fit

Table 3.--(cont'd)

BYTES Record 2 For RBV	ENCODED	DESCRIPTION
255-406	FP	Zero fill
407-742	FL	Internal distortion coefficients for transformation from input to nominal image space (42 values)
743-1078	FL	Internal distortion coefficients for transformation from nominal to image space (42 values)
1079-5388	FP	Zero fill

Table 4.--MSS projection-dependent-data records: Record byte assignments

Relative Ancillary Record Number	Byte	Row	Contents
3/11 1/	1-4	-	Record number
	5	-	Zero fill
	6	-	Record Type Code - 044_8
	7-250	1	HRS Pixel Coordinates (61)
	251-254	1	Line Fill Left Count
	255-258	1	Line Fill Right Count
	259-502	2	HRS Pixel Coordinates (61)
	503-506	2	Line Fill Left Count
	507-510	2	Line Fill Right Count
	511-3030	4-12	HRS Pixel Coordinates and Fill Counts
	3031-3596	-	Zero fill
4/12	1-6	-	Record ID as in Record 3
	7-3030	13-24	HRS Pixel Coordinates and Fill Counts
	3031-3596	-	Zero fill
5/13	1-6	-	Record ID as in Record 3
	7-3030	25-36	HRS Pixel Coordinates and Fill Counts
	3031-3596	-	Zero fill

1/ Relative record number m/n where m is relative number for the PS/UTM projection and where n is the relative number for the SOM projection. Relative record numbers 19-26 are zero filled.

Table 4.--(cont'd)

Relative Ancillary Record Number	Bytes	Row	Contents
6/14	1-6	-	Record ID as in Record 3
	7-3030	37-48	HRS Pixel Coordinates and Fill Counts
	3031-3596	-	Zero fill
7/15	1-6	-	Record ID as in Record 3
	7-762	49-51	HRS Pixel Coordinates and Fill Counts
	763-1014	-	Zero fill
	1015-1258	1	VRS Line Coordinates (61)
	1259-2966	2-8	VRS Line Coordinates
	2967-3596	-	Zero fill
8/16	1-6	-	Record ID as in Record 3
	7-2934	9-20	VRS Line Coordinates
	2935-3596	-	Zero fill
9/17	1-6	-	Record ID as in Record 3
	7-2934	21-32	VRS Line Coordinates
	2935-3596	-	Zero fill
10/18	1-6	-	Record ID as in Record 3
	7-2934	33-44	VRS Line Coordinates
	2935-3078	-	Zero fill

Table 4.--(cont'd)

Relative Ancillary Record Number	Bytes	Row	Contents
10/18(cont'd)	3079-3080	-	Pixel number of WRS in Fully Processed Image
	3081-3082	-	WRS offset from Fully Processed Image Center Pixel
	3083-3102	-	Temporal Registration Scene ID (20 ASCII)
	3103-3134	-	Scan line and Pixel numbers for Temporal Registration Marks P1, P2, P3, and P4 clockwise from upper left corner. Eight bytes for each point. Four bytes for line and four bytes for pixel.
	3135-3150	-	Scan line and Pixel numbers for 4 overlap marks. See Header bytes 215-230 for corrected MSS imagery.
	3151-3154	-	Actual number of tick marks
	3155-3162	-	Input Sample value of 4 corner points in output image (Location of image in output array)
	3163-3170	-	Orientation of image output coordinate system for either UTM or PS if record 10 or SOM if record 18 in radians (Beta UTM or Beta PS) in FL format.

Table 4.--(cont'd)

Relative Ancillary Record Number	Bytes	Row	Contents
	3171-3172	-	Number of sweeps prior to nadir at which ground points begin (BINARY).
	3173-3196	-	Zero fill.

Table 5.--RBV projection-dependent-data records: Record-byte assignments

Relative Ancillary Record Number	Bytes	Segment	Row	Contents
3/17 1/	1-4	-	-	Record number
	5	-	-	Zero fill
	6	-	-	Record Type Code - 044_8
	7-82	1	1	HRS pixel coordinate (19)
	83-86	1	1	Left fill count
	87-806	1	2-10	HRS pixel coordinates and left fill count
	807-882	2	1	HRS pixel coordinates (19)
	883-886	-	-	Zero fill (no fill for center segment)
	887-1606	2	2-10	HRS pixel coordinates and zero fill
	1607-1682	3	1	HRS pixel coordinates
	1683-1686	3	1	Right fill count
	1687-2406	3	2-10	HRS pixel coordinates and right fill counts
	2407-5388	-	-	Zero fill
4/18	1-6	-	-	Record ID as in Record 3
	7-5388	1-3	11-20	HRS pixel coordinates, fill counts, and zero fill
5/19	1-6	-	-	Record ID as in Record 3
	7-5388	1-3	21-30	HRS pixel coordinates, fill counts, and zero fill

1/ Relative record number m/n where m is relative number for the PS/UTM projection and where n is the relative number for the SOM projection.

Table 5.--(cont'd)

Relative Ancillary Record Number	Bytes	Segment	Row	Contents
6/20	1-6	-	-	Record ID as in Record 3
	7-5388	1-3	31-40	HRS pixel coordinates, line fill counts, and zero fill
7/21	1-6	-	-	Record ID as in Record 3
	7-5388	1-3	41-50	HRS pixel coordinates, line fill counts, and zero fill
8/22	1-6	-	-	Record ID as in Record 3
	7-5388	1-3	51-60	HRS pixel coordinates, line fill counts, and zero fill
9/23	1-6	-	-	Record ID as in Record 3
	7-5388	1-3	61-70	HRS pixel coordinates, line fill counts, and zero fill
10/24	1-6	-	-	Record ID as in Record 3
	7-486	1-3	71-72	HRS pixel coordinates, line fill counts, and zero fill
	487-5388	-	-	Zero fill
11/25	1-6	-	-	Record ID as in Record 3
	7-82	1	1	VRS line coordinates (19)
	83-158	1	2	VRS line coordinates (19)
	159-2058	1	3-27	VRS line coordinates
	2059-2062	-	-	Zero fill
	2063-4114	2	1-27	VRS line coordinates
	4115-5388	-	-	Zero fill

Table 5.--(cont'd)

Relative Ancillary Record Number	Bytes	Segment	Row	Contents
12/26	1-6	-	-	Record ID as in Record 3
	7-2058	3	1-27	VRS line coordinates
	2059-2062	-	-	Zero fill
	2063-4114	1	28-54	VRS line coordinates
	4115-5388	-	-	Zero fill
13/27	1-6	-	-	Record ID as in Record 3
	7-2058	2	28-54	VRS line coordinates
	2059-2062	-	-	Zero fill
	2063-4114	3	28-54	VRS line coordinates
	4115-5388	-	-	Zero fill
14/28	1-6	-	-	Record ID as in Record 3
	7-2058	1	55-81	VRS line coordinates
	2059-2062	-	-	Zero fill
	2063-4114	2	55-81	VRS line coordinates
	4115-5388	-	-	Zero fill
15/29	1-6	-	-	Record ID as in Record 3
	7-2058	3	55-81	VRS line coordinates
	2059-5388	-	-	Zero fill
16/30	1-6	-	-	Record ID as in Record 3
	7-8	-	-	Pixel number of WRS in fully processed image

Table 5.--(cont'd)

Relative Ancillary Record Number	Bytes	Segment	Row	Contents
16/30(cont'd)	9-10	-	-	Scan line number of WRS in fully processed image
	11-30	-	-	Temporal registration scene ID (20 ASCII)
	31-62	-	-	Scan line and pixel number for P1, P2, P3, P4
	63-66	-	-	Number of tick marks for top, left, right, bottom (binary)
	67-390	-	-	Computed Reseau locations, 81 sets of coordinates
	391-406	-	-	Line and sample values of 4 corner points in output image (location of image data in output array)
	407-414	-	-	Orientation of image output coordinate system for UTM or PS if record 16 and for SOM/HOM if record 30. Beta in radians.
	415-426	-	-	Number of fill lines to be used for each segment before image data. Three fixed point binary (FP) values.
	427-438	-	-	Number of input image lines to be skipped for each segment at top of image. Three FP values.
	439-1238	-	-	Top left fill counts - up to 200 FP values
	1239-2038	-	-	Top right fill counts - up to 200 FP values
	2039-2838	-	-	Bottom left fill counts - up to 200 FP values

Table 5.--(cont'd)

Relative Ancillary Record Number	Bytes	Segment	Row	Contents
16/30 (cont'd)	2839-3638	-	-	Bottom right fill counts - up to 200 FP values
	3639-5388	-	-	Zero fill

ANNOTATION RECORDS

The annotation records contain all of the alphanumeric information printed on the bottom of standard film products and the tick information that surrounds the corrected and framed image (table 6). For a CCT-AM or CCT-AR, within the attributes are two annotation records (SOM and UTM or PS) for each band or subscene. The record content is projection dependent and is as it would be on a corrected CCT for each projection.

All tick-mark information is given in bytes 122-2256 of the annotation record. Figure 11 shows the relationship the alphanumeric annotation and tick-mark information to the image array. Each tick mark is 9 bytes and represents a ground distance of 1000 meters. Figure 12 illustrates the tick mark features and their proper interpretation of the tick mark location bytes (first two bytes). Figure 13 illustrates the format of UTM and PS tick mark annotation. The order of the tick mark data on the CCT is summarized as follows:

TICK MARK ZONE	ORDER OF APPEARANCE
Top	Left to right
Left	Top to bottom
Right	Top to bottom
Bottom	Left to right

TABLE 6.--Annotation record: Record-byte assignments

Bytes	Description
1-4	Record number
5	Zero fill
6	Record Type Code: 333_8
7-14	Day, month, year of exposure (ASCII), e.g., 07JUN⌀76
15-31	Format center - latitude and longitude at the center of the MSS and RBV images format are indicated in degrees and minutes (ASCII): e.g., C⌀N33-05/W115-18
32-40	Nominal path row identifier (ASCII), e.g., D202-101. "D" indicates descending acquisition; "A" indicates ascending acquisition. The path is 202, row is 101.
41-57	Nominal latitude and longitude (ASCII), e.g., N⌀N33-03/W115-42
58-67	Characters in this group are ASCII and sensor and spectral band dependent
FOR RBV	
58-62	Sensor spectral band identification code
63-64	RBV shutter duration code (shutter speed in msec): XA=2.4, XB=4.0, XC=5.6, XD=8.0, XE=12.0

TABLE 6.--(cont'd)

Bytes	Description
65	Aperture correction indicator: I--aperture correction "in" O--aperture correction "out" ƀ--blank
66	Transmission: D--direct transmission R--stored data played back from the satellite WBUT recorder
67	Blank
FOR MSS	
58-64	The sensor spectral-band identification code
65	Blank
66	Transmission: D--direct transmission R--stored data played back from the satellite WBUT recorder
67	Blank
68-81	Sun angles - the sun-elevation angle and sun-aximuth angle measured clockwise from true North at the time of RBV exposure or midpoint of MSS frame is specified to the nearest degree. Blank for ascending node coverage. (ASCII)
82	Type of correction applied: (ASCII) U--uncorrected S--system G--geometric correction based on geometric GCP's R--geometric correction based on relative GCP's

TABLE 6.--(cont'd)

Bytes	Description
83	Scale of image: (ASCII) 1--185 km x 185 km 2--99 km x 99 km 3--185 km x 170 km
84	Projection: (ASCII) L--Lambert projection P--Polar stereographic projection S--Space oblique mercator projection U--Universal transverse mercator projection H--Hotine oblique mercator projection
85	"-" (ASCII)
86	Resampling algorithm: (ASCII) C--cubic convolution N--nearest neighbor
87	Type of ephemeris data used to compute image center: (ASCII) P--predictive D--definitive (for system level correction only)
88	"-" (ASCII)
89	Processing procedure: (ASCII) A--abnormal N--normal
90	Defines whether an earth image or RBV calibration image has been processed: (ASCII) Blank - earth image Either 0, 1, or 2 - RBV radiometer calibration images, indicating lowest to highest exposure level respectively.
91	Sensor gain options: (ASCII) H--high gain L--low gain

TABLE 6.--(cont'd)

Bytes	Description
92	Type of MSS transmission: (ASCII) 1--linear mode 2--compressed mode
93	Blank (ASCII)
94-106	Agency and project: (ASCII) NASA Landsat
107-121	Frame identification number. (ASCII) Each image has a unique identifier which will contain encoded information consisting primarily of time of exposure relative to launch. Its format is: E-ADDDD-HHMMS-B and is interpreted as follows: E = Project identifier A = Mission: 1-Landsat 1 2-Landsat 2 3-Landsat 3 DDDD = Day number, relative to launch at time of observation HH = Hour at time of observation MM = Minute at time of observation S = Tens of seconds at time of observation B = Image code: RBV - A, B, C, D MSS - 4, 5, 6, 7, 8
122-404	Zero fill
405-548	Top edge tick mark data, 16 coordinates (9 bytes each)
549-802	Zero fill
803-964	Left side tick mark data, 18 coordinates (9 bytes each)
965-1200	Zero fill
1201-1263	Left side tick mark data (concluding) 7 coordinates (9 bytes each)

Table 6.--(cont'd)

Bytes	Description
1264-1598	Zero fill
1599-1760	Right side tick mark data, 18 coordinates (9 bytes each)
1761-1996	Zero fill
1997-2059	Right side tick mark data (concluding) 7 coordinates (9 bytes each)
2060-2394	Zero fill
2395-2538	Bottom edge tick mark data, 16 coordinates (9 bytes each)
2539-3596 if MSS	Zero fill
2539-5388 if RBV	Zero fill

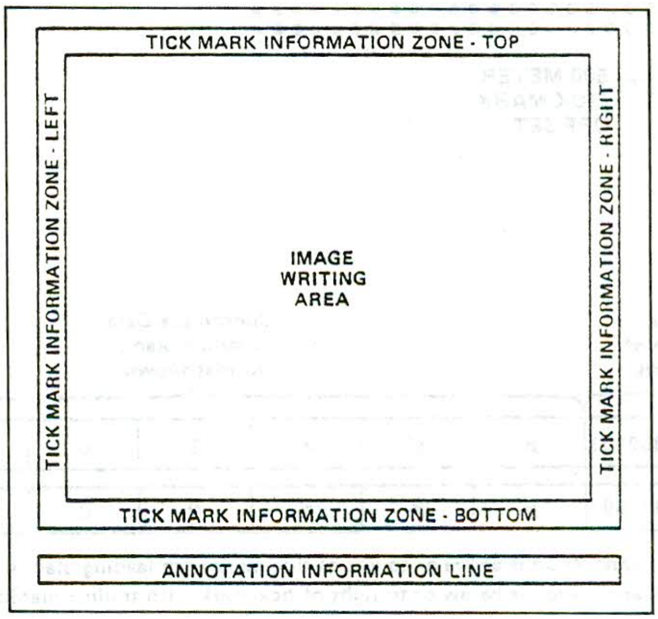


Figure 11.--Standard placement of CCT annotation information on film products.

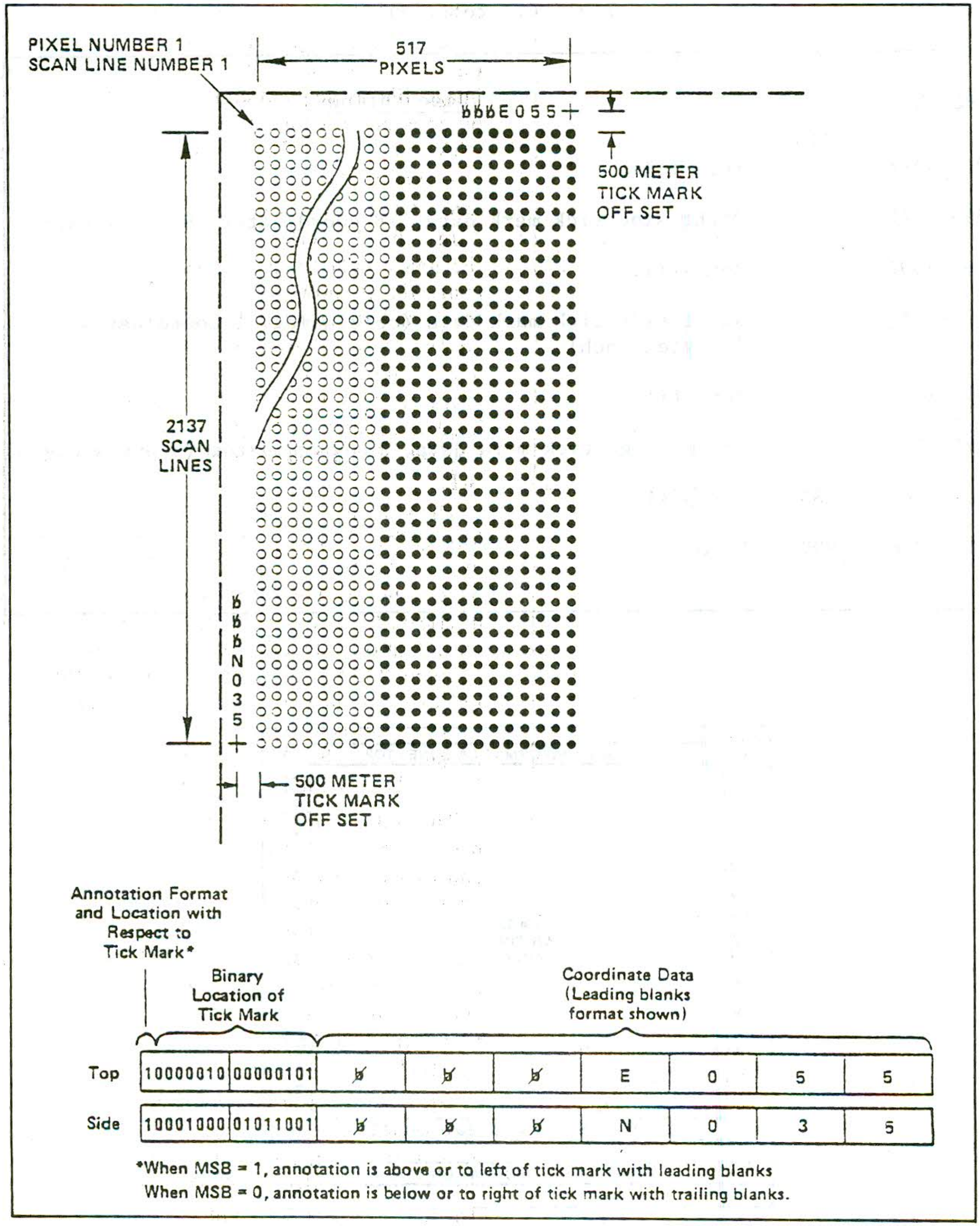


Figure 12.–An example of the placement of two tick-mark coordinates and their corresponding annotation with respect to fully processed image data.

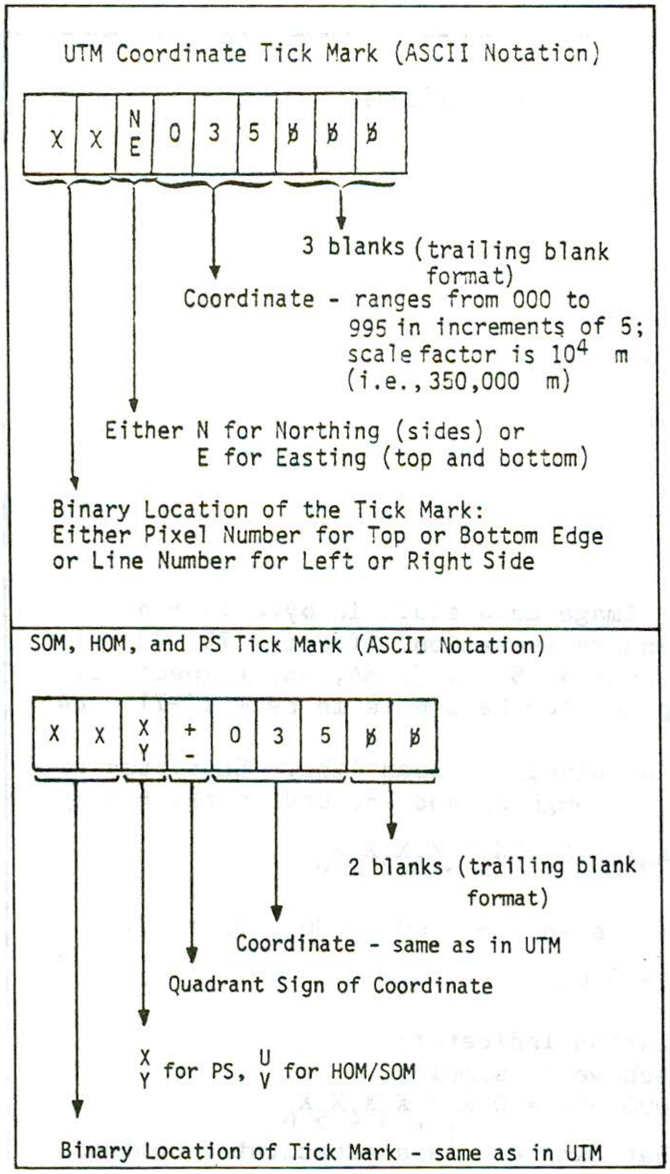


Figure 13.–Examples of tick-mark annotation for UTM and PS.

IMAGE DATA FILE

The image-data file contains the image-data records as shown in tables 7-10 and figures 14 and 15. Each record contains sensor data representing one scan line plus the calibration and quality data associated with that scan line. The header record described above gives the image data characteristics including the number of pixels per scan line, interleaving, and so forth. The content of the image file depends on the interleaving and correction status of the data.

BAND SEQUENTIAL

In a band sequential (BSQ) format, the image data for each band is given in a separate image file as sequential records for the total number of scan lines in the image array. For RBV data, the CCT set is as if it were BSQ for only one band.

BAND INTERLEAVED BY LINE

In a band interleaved by line (BIL) format, the image data for all bands are given in one image file as shown in figure 9. If the the data for a band are missing, the band image data will be zero filled. As each record still contains one line of one band, the record lengths are not changed. Although each band of BSQ requires header, annotation, ancillary, and trailer data, one set of these is sufficient for all bands of BIL.

The scan lines of BIL are sequenced by interleaving four bands of Landsat-1 or -2 MSS data or five bands of Landsat-3 MSS data. Where bands are missing, zero-filled scan lines are interleaved. For example, Landsat-3 while ascending only acquires band 8 data. If a scene of band 8 data were requested in BIL format, the CCT would contain five bands interleaved as four records of zeros followed by one record of valid data. Figure 16 shows the layout difference between BIL and BSQ.

The values of the pixels on the CCT-AM have been radiometrically corrected using gain and offset values, and decompressed using a decompresssion look-up table. The gain and offset values are provided in bytes 3577-3584 of each record. It should be noted, however, that the radiometric correction process is *not* uniquely reversible because of computational roundoffs and dual entries in the decompression tables.

The quality of each scan line is recorded in each scan-line record as Q0, Q1, Q2, and Q3. A quality code of Q0 is assessed when no faults are known. A quality of Q1 is assessed when the output line is determined from input lines, any of which were synthetically generated during the preprocessing state at GSFC. A quality of Q2 is assessed when the output line

Table 7.--MSS uncorrected image-data record

Bytes	Data	Description
1-4	XXX XXX XXX XXX	Record number
5	000	Zero fill
6	355_8	Record type code
7-12	XXX XXX XXX XXX XXX XXX	Scan line count See Figure 14
13-3560	XXX XXX ⋮ XXX XXX	Image pixels. Image data start in byte 13 + offset for band-to-band registration. Offset = 75, 73, 71, 69, 3, 0 for bands 4, 5, 6, 7, 8A, 8B, respectively. (First image pixel for band 6 is in byte 13+71 = 84)
3561-3562	XXX XXX	Binary number of pixels in scan line. Encrypted as binary bits X_{11} through X_0 and encoded in the two bytes as: $00X_{11}X_{10}X_9X_8X_7X_6 00X_5X_4X_3X_2X_1X_0$
3563	XXX	Quality code for scan line: Q0 = 000_8, Q1 = 077_8, Q2 = 007_8, Q3 = 070_8
3564	XXX	Nominal calibration indicator: 1 bit for each wedge sample; eg 010_8 = 00001000 = $00X_1X_2X_3X_4X_5X_6$ indicates that sample 3 is a substituted nominal.
3565-3570	XXX XXX XXX XXX XXX XXX	Selected cal. wedge values: 6 binary value ranging 0-63
3571-3576	000 000 000 000 000 000	Zero fill
3577-3580	XXX XXX	Gain value

TABLE 7.--(cont'd)

	Data	Description
	XXX XXX	Represents the signed 16 bit number applied in the radiometric correction process. Upper 4 bits of each byte are zero filled. $0000X_{15}X_{14}X_{13}X_{12}0000X_{11}X_{10}X_9X_8 0000X_7X_6X_5X_4 0000X_3X_2X_1X_0$
3581-3584	XXX XXX XXX XXX	Bias value: Represents the signed 16 bit number applied in the radiometric correction process. The format is the same as for bytes 3577-3580
3585-3596	000 000	Zero fill

TABLE 8.--MSS fully corrected image-data record

Bytes	Data	Description
1-4	XXX XXX XXX XXX	Record Number
5	000	Zero Fill
6	355_8	Record Type Code
7-9	XXX XXX XXX	Scan Line Count - binary Quality Code: Q0 - 300_8 Q1 - 011_8 Q2 - 022_8 Q3 - 333_8
10	XXX	Left fill and right fill counts
11-12	XXX XXX	Binary Value: LFC is left-most 12 bits RFC is right-most 12 bits
13-3560	XXX XXX XXX XXX	Image Pixels: binary 0-127
3561-3596	177 177 177 177	One's Fill

Table 9.--RBV uncorrected image-data record

Bytes	Data	Description
1-4	XXX XXX XXX XXX	Record Number
5	000	Zero Fill
6	355_8	Record Type Code
7-12	XXX XXX XXX XXX XXX XXX	Scan Line Count See Figure 15
13-5387	XXX XXX XXX	Image Pixels: binary 0-127
5388	XXX	Scan Line Quality Q0 - 000_8 Q1 - 077_8 Q2 - 007_8 Q3 - 070_8

BYTE ASSIGNMENT	MSB 0 1 2 3	4 5 6 7	8 9 10 11	LSB 12 13 14 15	0 1 2 3	4 5 6 7	8 9 10 11	12 13 14 15	0 1 2 3	4 5 6 7	8 9 10 11	12 13 14 15
BIT WEIGHT	8 4 2 1	8 4 2 1	8 4 2 1	8 4 2 1	8 4 2 1	8 4 2 1	8 4 2 1	8 4 2 1	8 4 2 1	8 4 2 1	8 4 2 1	8 4 2 1
CONTENTS	Hun	Ten	Unit	Ten	Unit	Ten	Unit	Ten	Unit	Hun	Band Indicator	Binary Count*
	Day of Year			Hours		Minutes		Seconds		Millis.		
EXAMPLE	0 0 0 1	1 0 0 1	0 1 0 1	0 0 1 0	0 0 0 1	0 1 0 1	0 1 1 1	0 0 0 1	0 0 1 0	0 0 1 1	0 1 0 0	0 1 1 1

EXAMPLE = Day of Year 195, Hour 21, Minute 57, Second 12, Millisecond 300, Band 4, Binary Count 7

*Binary count will be reset to zero every other mirror sweep by the time increment. Hence it will run from $1\text{-}12)_{10}$ for each band number.

Figure 14.–Scan-line count for MSS.

TABLE 10.--RBV corrected image-data record

Bytes	Data		Description
1-4	XXX	XXX	Record Number
	XXX	XXX	
5	000		Zero Fill
6		355_8	Record Type Code
7-8	XXX	XXX	Binary count of scan line
9-10	XXX	XXX	Left fill count - binary
11-12	XXX	XXX	Right full count - binary
13-5334	XXX	XXX	Image Pixels: binary 0-127
	XXX	XXX	
5335-5336	177_8	177_8	Ones fill
5337	XXX		Scan line quality code: Q0 - 000_8 Q1 - 077_8 Q2 - 007_8 Q3 - 070_8
5338		177_8	Ones fill
5339-5388	177_8	177_8	Ones fill

BYTE ASSIGNMENT:	MSB 0 1 2 3	4 5 6 7	8 9 10 11	12 13 14 15 LSB	0 1 2 3	4 5 6 7	8 9 10 11	12 13 14 15	0 1 2 3	4 5	6 7 8 9 10 11 12 13 14 15
BIT WEIGHT:	8 4 2 1	8 4 2 1	8 4 2 1	8 4 2 1	8 4 2 1	8 4 2 1	8 4 2 1	8 4 2 1	8 4 2 1	2 1	2^9 .... 2^0
CONTENTS:	Hun	Ten	Unit	Ten	Unit	Ten	Unit	Ten	Unit	Cam. #	Scan Line No.
	SPACE CRAFT TIME: Day of Year			Hours		Minutes		Seconds			
EXAMPLE:	0 0 0 1	1 0 0 1	0 1 0 1	0 0 1 0	0 0 0 1	0 1 0 1	0 1 1 1	0 0 0 1	0 0 0 0	1 0	0 0 0 0 0 0 1 1 1 1

EXAMPLE = Day of Year 195, Hour 21, Minute 57, Seconds 10, Camera 2, Scan Line 15

Figure 15.–Scan-line count for RBV.

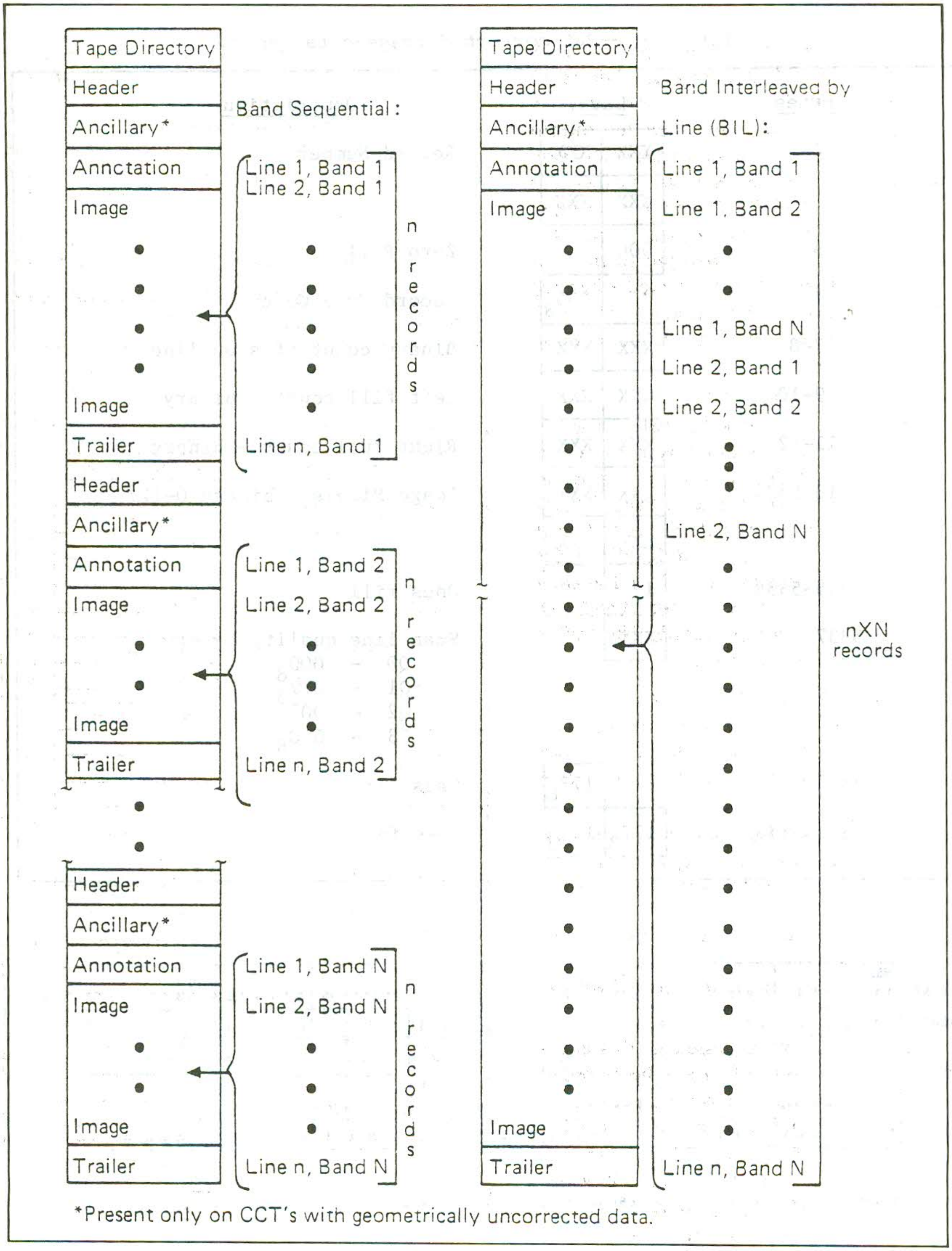


Figure 16.–Examples of interleaving of MSS image data of N bands of n lines each.

is determined from input lines, any of which were synthetically filled during the data input process, for example, owing to loss of sync. A quality of Q3 is assessed when the output line is determined from data synthetically generated during the output process, such as, top or bottom lines of all fill. When more than one quality assessment affects the output line, the most severe assessment is assigned to the output line, for instance, Q3 is assigned when Q2 and Q3 occur. Also, quality conditions identified with specific scan lines are reflected in all resulting scan lines.

TRAILER FILE

The trailer file provides the values used if digital enhancement techniques were applied to the image data. Trailer records are band dependent and are present for each band. Therefore, in BSQ, each image data file is followed by a trailer file containing that band's trailer record. In BIL, the image data file is followed by one trailer file containing four (Landsat-1 and -2) or five (Landsat-3) records. The trailer content is specified in table 11.

MULTI-VOLUME CCT SET

Depending on sensor, interleaving, density, and number of bands, one scene may require more than one volume. For a multi-volume tape set:

1) Each volume will begin with a tape directory.
2) The transition between volumes will be at file boundaries or record boundaries within the image file only.
3) All volumes except the last of the set will end with an EOV.
4) The last volume of the set will end with an EOS.

For the application addressed in this document, the exact amount of data to be recorded on each volume of a set is given for each possible type of data configuration shown in table 12. The data allocations for each volume of a CCT tape set are determined by the following:

1) Tape directory files, scene attributes files, and trailer files are not mentioned but are assumed to be on the tapes in the relative locations as given.
2) Tape break points are on an integral record boundary within the image file or after an EOF of an entire band.
3) Break point of an image file is done:
   a) with equal distribution, or if it does not divide evenly, then the lower number goes on the first tape with the residual on the last;
   b) if BIL, the number of records must be divisible by the number of lines interleaved.

Figure 17 gives some illustrations of transitions between volumes of a CCT set.

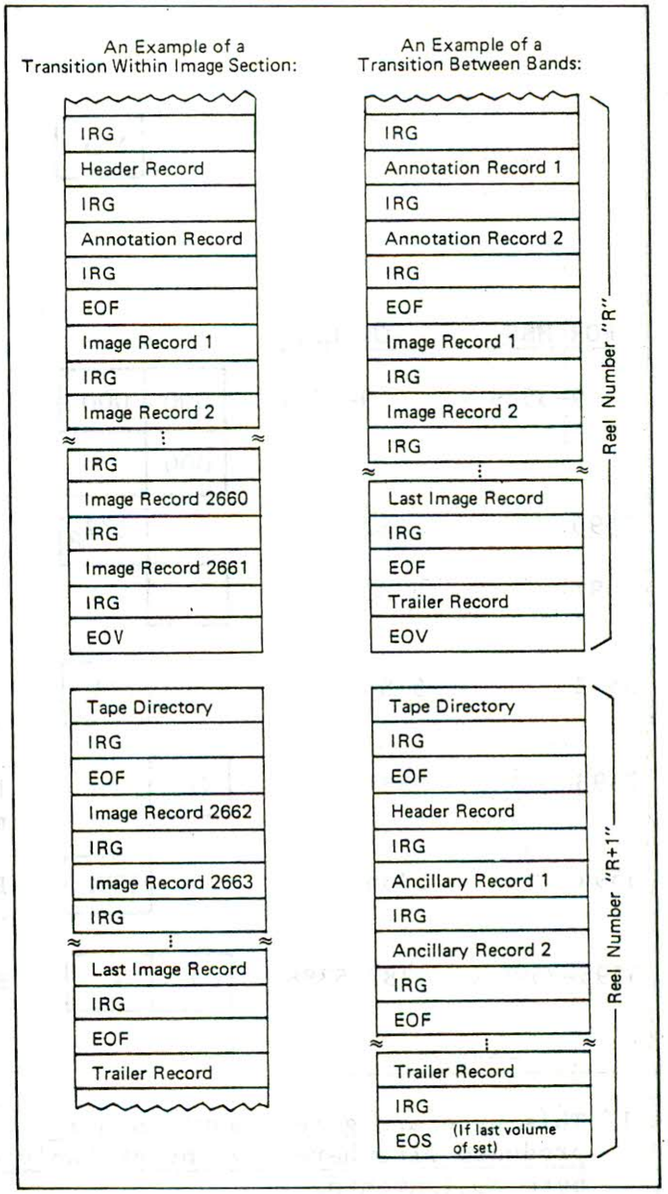


Figure 17.–Illustrations of transition between volumes of a CCT tape set.

TABLE 11.--Trailer record: Record-byte assignments 1/

Bytes		Data		Description
1-4		XXX	XXX	Record number: for BSQ always 1, for BIL 1-a.
5		000		Zero fill
6			366_8	Record type code
7		XXX		Flag for last scene (each image) in a data acquisition pass or swath: 000_8 = No; 377_8 = Yes
8			XXX	Flag for last scene (each image) on the HDT: 000_8 = No; 377_8 = Yes
FOR MSS	FOR RBV			
9-3589	9-5381	000	000	Zero fill
		000		
3590	5382		377_8	Destriped image
3591	5383	G		Units of contrast stretch values ASCII' G'= gray levels
3592	5384		XXX	Binary units of contrast enhancement minimum
3593	5385	XXX		Binary units of contrast enhancement maximum
3594	5386		XXX	Binary radiance value used for atmo-spheric scatter compensation
3595-3596	5387-5388	J	K	Edge enhancement kernal size: J x K; J-pixels in x direction (binary); K-pixels in y direction (binary)

1/ This byte assignment applies only to CCT's produced by EDIPS; tapes produced elsewhere may and probably will have different trailer record byte assignments.

TABLE 12.--Break points of multi-volume CCT sets

Data Type and Tape Number		Image Distribution by Density 800 BPI	1600 BPI
RBV			
Geometrically uncorrected			
	Tape 1	2062 lines	entire image
	Tape 2	remaining image lines	
Geometrically corrected			
	Tape 1	2661 lines	entire image
	Tape 2	2661 lines	
MSS BSQ			
Geometrically uncorrected			
(1 band)	Tape 1	entire image	entire image
(2 bands)	Tape 1	band 1	all images
	Tape 2	band 2	
(3 bands)	Tape 1	bands 1 and 2	all images
	Tape 2	band 3	
(4 bands)	Tape 1	bands 1 and 2	all images
	Tape 2	bands 3 and 4	
(5 bands)	Tape 1	bands 1 and 2	bands 1, 2, and 3
	Tape 2	bands 3 and 4	bands 4 and 5
	Tape 3	band 5	
Geometrically corrected			
(1 band)	Tape 1	entire image	entire image
(2 bands)	Tape 1	band 1 and 1491 lines of band 2	all images
	Tape 2	1492 lines of band 2	
(3 bands)	Tape 1	band 1 and 1491 lines of band 2	all images
	Tape 2	1492 lines of band 2 and band 3	
(4 bands)	Tape 1	band 1 and 1491 lines of band 2	bands 1 and 2
	Tape 2	1492 lines of band 2 and band 3	bands 3 and 4
	Tape 3	band 4	
(5 bands)	Tape 1	band 1 and 1987 lines of band 2	bands 1, 2, and 3
	Tape 2	996 of 2, band 3, and 996 of 4	bands 4 and 5
	Tape 3	1987 lines of band 4 and band 5	

TABLE 12.--(cont'd)

Data Type and Tape Number		Image Distribution by Density	
		800 BPI	1600 BPI
MSS BIL			
Geometrically uncorrected			
(4 bands)	Tape 1	4800 lines	all lines
	Tape 2	4800 lines	
(5 bands)	Tape 1	4000 lines	6000 lines
	Tape 2	4000 lines	6000 lines
	Tape 3	4000 lines	
Geometrically corrected			
(4 bands)	Tape 1	3976 lines	5964 lines
	Tape 2	3976 lines	5968 lines
	Tape 3	3980 lines	
(5 bands)	Tape 1	4970 lines	7455 lines
	Tape 2	4970 lines	7460 lines
	Tape 3	4975 lines	

APPENDIX A

GEOMETRIC CORRECTION OF CCT-AM OR CCT-AR

(TO BE PROVIDED)

APPENDIX B

SYSTEMATIC GEOMETRIC CORRECTIONS

When a Landsat image is corrected, the image data are processed in the steps discussed in Appendix A. During this transformation from geometrically uncorrect to correct, the image data are contorted to match spatial relationships as they are on Earth and as represented by the given projection. During this transformation, the image data must be corrected for the following high frequency geometric errors:

1) Band-to-band offsets
2) Line length
3) Earth rotation
4) Detector-to-detector sampling delay

On a CCT-PM, all of the corrections described in this appendix have been applied to the image data. For a CCT-AM, these corrections have not been applied.

Appendix A, subprocess 3 requires the algorithm necessary to correct for these errors. This correction only applies to a CCT-AM. RBV subscenes do not reflect any of these errors.

This appendix shows the derivation of the complete correction algorithm. Either the full algorithm or any subset may be used in sub–process 3 of Appendix A.

BAND-TO-BAND OFFSETS

The physical layout of detectors causes each band on Landsat MSS to be offset in along-scan direction relative to the other: integral pixel–offset corrections have been applied to the data contained on a CCT-AM by shifting the pixels within a line. Any fractional pixel offsets (first detector of band 8 is an exception) must be applied during horizontal resampling. The HRS coordinates provided in ancillary data are de–rived for band four. These pixels coordinates (HR in Appendix A - interpolated to obtain HR′) must be adjusted for each of the other bands. Preliminary values of fractional band sample offsets (SO_i) are given in the table below:

Band-Band Offsets

Band, i	$-SO_i$, pixels
4	0
5	−0.09
6	−0.18
7	−0.27
8A	−3.90
8B	−0.45

For this correction, the calculation of HR′ (subprocess 3 in Appendix A) is given by:

$$HR' = HR - SO_i$$

These physical offsets are dependent on the mirror velocity since the number of pixels re–quired to cover the angle or translation offset is a function of velocity. A more extensive correction being considered would result in an algorithm of the form: $HR' = (HR) - k_1 SO_i - k_2 SO_i (HR) - k_3 SO_i (HR)^2$, where k_1, k_2, k_3 are mirror-velocity coefficients given in bytes 71-102 of ancillary record one on CCT-AM. The band-to-band offsets ($S0_i$) will be given in bytes 263-282 of ancillary record one on CCT-AM.

LINE LENGTH VARIATIONS

The variation in the number of image pixels per line requires a scale correction of the form $\left(\frac{I_R}{I_N}\right) HR$ where I_R is the actual line length of image data and I_N is the nominal line length expected. Preliminary analysis indicated that I_N = 3,173 pixels/line. Combining this correction with previous result HR′ would be defined by:

$$HR' = \left(\frac{I_R}{I_N} - k_2 SO_i\right)(HR) - k_1 SO_i - k_3 SO_i (HR)^2$$

The actual line length I_R is given in the first two words of supporting data following each image line on the CCT–AM.

APPENDIX B

EARTH ROTATION

Earth rotation is included in the geometric modeling which generates the HRS-VRS geometric grid. However, this modeling only accounts for the location of the center (line = 3.5) of a six – line mirror sweep. The linear interpolation between HRS (from HRS table) to obtain HR applies Earth rotation as though each line were scanned separately. The correction for this effect will be given by:

$$\left(\frac{I_R}{I_N} \cdot \frac{K_L}{K_S}\right) (3.5 - d) \propto eR$$

where:

$\frac{I_R}{I_N}$ = previously defined line length factor

$\frac{K_L}{K_S}$ = correction for nominal line-pixel spacing

$K_L \sim 79$ meters $\quad K_S \sim 58.4$ meters

$\propto eR$ = earth rotation parameter
(bytes 135-138, ancillary record 2, CCT-AM)

d = detector number associated with a line

DETECTOR-TO-DETECTOR SAMPLING DELAY

Due to mirror motion during finite sampling interval, the six lines of a sweep are offset as given by the table below:

Sampling Delay

Detector, d	Delay, pixels (SD_d)
1	.20
2	.12
3	.04
4	–.04
5	–.12
6	–.20

The sampling-delay constants (SD_d) are given in bytes 159-262, ancillary record 1, CCT-AM. Combining the Earth rotation and sampling–delay corrections with the previous result, the complete algorithm which defines HR′ is:

$$HR' = \left(\frac{I_R}{I_N} \cdot \frac{K_L}{K_S}\right)(3.5\text{-}d) \propto eR - k_1 SO_i + SD_d$$

$$+ \left(\frac{I_R}{I_N} - k_2 SO_i\right) (HR) - k_3 SO_i \; (HR)^2$$

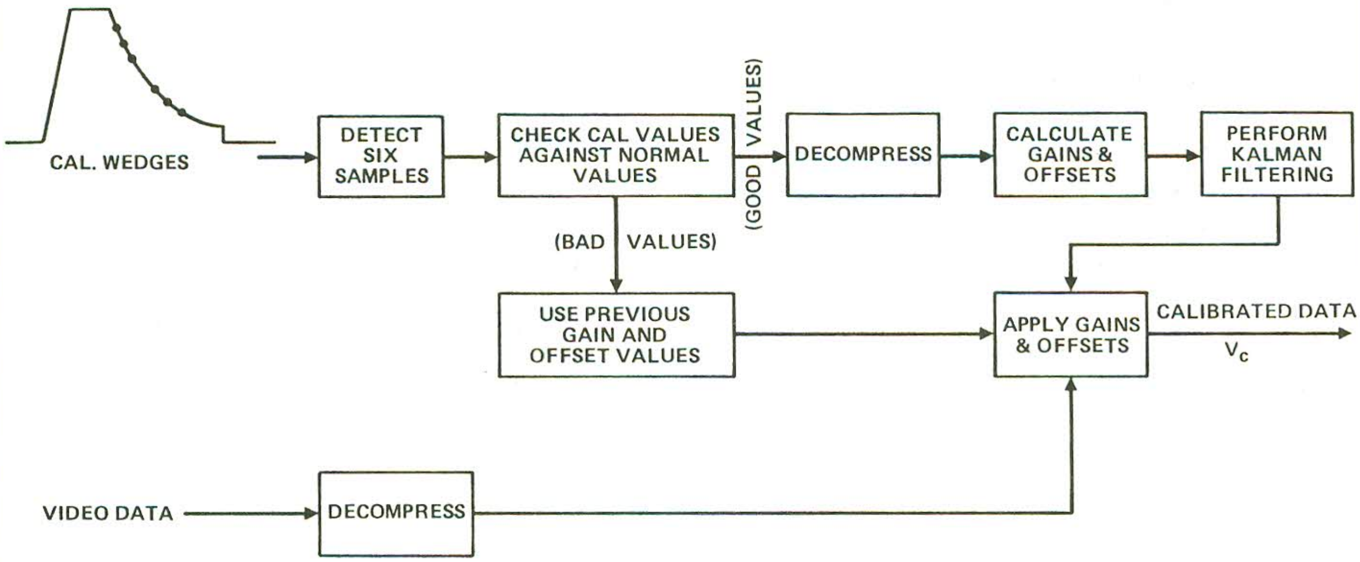
The above review is the preliminary formulation of high frequency corrections required in applying the geometric grid data on a CCT-AM. The final formulation will be derived when final calibration data is available on the Landsat-3 MSS sensor.

APPENDIX C

MSS RADIOMETRIC CORRECTION

The radiometric-calibration algorithm, shown in figure C-1, applies in general to all IPF-cor–rected Landsat MSS data. The differences in the radiometric corrections as they are applied to the various bands of Landsats 1, 2, and 3 are the determination of the values assigned to the variables used in the algorithm. All radiometric calibration and data decompression are done by the master data processor (MDP), wherein the algorithm and look-up tables reside. The flow of processing steps within the MDP is also shown in figure C-1. If the data are acquired in the compressed mode, the inverse of the spacecraft compression is applied to both video and calibration-wedge values before the radiometric corrections are calculated and applied. The decompressed values, ranging from 0 to 127, which are associated with the compressed input values, ranging from 0 to 63, are given in Appendix E. Description of the elements of the $V_c = \left(\frac{K}{M \cdot b}(V\text{-}a)\right) - A$ algorithm follows.

RADIOMETRIC CALIBRATION ALGORITHM
(For Compressed Mode)



$$V_c = \left[\frac{K}{M \cdot b}(V\text{-}a)\right] - A$$

WHERE:

V_c	=	CALIBRATED IMAGE DATA (0-127)
A	=	OFFSET MODIFIER
K	=	MAXIMUM IMAGE COUNT (e.g., 127)
M	=	GAIN MODIFIER
V	=	DECOMPRESSED INPUT IMAGE DATA (0-127)
a	=	FILTERED OFFSET VALUE
b	=	FILTERED GAIN VALUE

Figure C-1 .— MSS radiometric–calibration algorithm.

V_c = calibrated pixel value, which will range from 0 to 127 for 7-bit pixels

K = maximum possible value for V_c (127 for 7-bit pixels)

a = the filtered offset value

b = the filtered gain value

a and b are determined as follows:
For band 8 *(thermal IR band)* a, b are defined as:

$$a = \frac{N_R V_O - N_C V_R}{N_R - N_C}, \quad b = \left(\frac{V_R - V_O}{N_R - N_C}\right)\Delta N$$

where N_R = black body reference radiance;

N_C = "cold" reference radiance;

V_R = corresponding pixel value (relative radiance), for N_R, determined by averaging 6 samples, extracted from alternate mirror sweeps on the input raw data HDT (HDT-F);

V_0 = corresponding pixel value(relative radiance) for N_C; and

N = Nmax – Nmin, the range betweeen maximum and minimum radiances of the IR detectors.

V = input pixel value (from 0 to 127 for 7-bit pixels)
M = multiplicative gain modifier
A = additive offset modifier

M and A are detector-dependent parameters used to control long term drifts in relative detector responses. They are derived by analyzing Landsat data over a period of time to determine the frequency with which these para– meters need updating in order to equalize detector gain and offset changes. At launch, M = 1 and A = O.

For all other bands, a and b are determined once per scan line as follows:

First, estimates of a and b (a and b) are made from the calibration data using the equations:

$$\left.\begin{aligned} \hat{a} &= \sum_{i=1}^{6} C_i V_i \\ \hat{b} &= \sum_{i=1}^{6} D_i V_i \end{aligned}\right\} \text{Linear regression}$$

Where V_i is the input value of the calibration wedge word i, and C_i and D_i are regression coefficients which are determined on the basis of prelaunch radiance tests. See tables C-1 through C-6 for the C_i's and D_i's. Then, a and b are filtered for every scan line, n, as follows:

$$b(n) = \begin{cases} \hat{b}(n) & \text{, for } n=1 \\ b(n-1) + W(n) \cdot \left[\hat{b}(n) - b(n-1)\right] & \text{, for } n>1 \end{cases}$$

$$a(n) = \begin{cases} \hat{a}(n) & \text{, for } n=1 \\ a(n-1) + W(n) \cdot \left[\hat{a}(n) - a(n-1)\right] & \text{, for } n>1 \end{cases}$$

Table C-1 .—— Landsat 1 C_i's and D_i's: Low gain decompressed.

Sensor	D_1	C_1	D_2	C_2	D_3	C_3	D_4	C_4	D_5	C_5	D_6	C_6
Band 4												
1	1.036133	- .108398	.854736	- .065918	- .247559	.191650	- .352783	.216309	- .601807	.274658	- .688477	.294922
2	1.047363	- .188477	.862793	- .114258	- .251709	.332764	- .357422	.375244	- .606934	.475342	- .694092	.510254
3	1.116943	- .140137	.913574	- .084961	- .273926	.237061	- .383301	.266602	- .640869	.336426	- .732178	.361328
4	1.009521	- .131592	.826172	- .077393	- .250244	.240479	- .348877	.269775	- .578613	.337646	- .657471	.360840
5	1.096191	- .140869	.894043	- .083740	- .273193	.246582	- .378906	.276611	- .625732	.346436	- .712158	.370850
6	1.114258	- .171387	.914551	- .102539	- .272217	.305664	- .382568	.343750	- .641846	.433105	- .731934	.464111
Band 5												
7	1.062500	- .108154	.754639	- .044922	- .293701	.170654	- .366943	.185791	- .537109	.220703	- .619385	.237793
8	1.057373	.211914	.765137	.093750	- .283936	- .330322	- .361572	- .361572	- .543701	- .435303	- .633057	- .471436
9	1.049805	- .195068	.750488	- .082764	- .287354	.307129	- .361328	.334717	- .533691	.399658	- .617432	.431152
10	1.077393	- .163818	.777100	- .071533	- .291016	.255859	- .369141	.279297	- .552246	.335937	- .641846	.363525
11	1.041992	- .125000	.744873	- .053711	- .284668	.192383	- .358154	.209961	- .530029	.250977	- .613770	.271240
12	1.092285	- .212646	.784180	- .093506	- .296143	.324219	- .374268	.354492	- .557861	.425293	- .647705	.460205
Band 6												
13	1.118652	.629883	.769043	.247070	.240479	- .331787	- .647949	-1.305176	- .703125	-1.365723	- .777100	-1.446777
14	1.104980	- .008057	.773437	- .003174	.259521	.003906	- .647705	.017090	- .706055	.018066	- .784424	.019043
15	1.146484	- .170654	.805664	- .070313	.273926	.085938	- .673828	.364746	- .735107	.382812	- .817383	.406982
16	1.285645	.382812	.902100	.153320	.30443	- .204590	- .755615	- .839355	- .823242	- .879883	- .913574	- .934082
17	1.256104	- .166016	.873535	- .064697	.284668	.091064	- .733643	.360840	- .797607	.377930	- .882812	.400391
18	1.157227	- .175049	.808594	- .070068	.270752	.092529	- .677490	.379639	- .737793	.397949	- .818848	.422607
Band 7												
19	1.533203	- .180664	1.105713	- .083984	.583496	.034180	- .984863	.389893	-1.079834	.411377	-1.157471	.428955
20	1.715088	- .184326	1.236816	- .086426	.652832	.032959	-1.101562	.392090	-1.207764	.413818	-1.294922	.431641
21	1.628174	- .181885	1.169189	- .083496	.610840	.035645	-1.043701	.389893	-1.142090	.411133	-1.222656	.428223
22	1.874512	- .177490	1.369141	- .084717	.743652	.030029	-1.212646	.389160	-1.336426	.411865	-1.438477	.430664
23	1.934570	- .171631	1.399902	- .078125	.744385	.036377	-1.245605	.384521	-1.366943	.405518	-1.466309	.423096
24	1.704102	- .170898	1.218018	- .074707	.629395	.041748	-1.090088	.382568	-1.189941	.402344	-1.271484	.418701

14	.4412859	-.0638097	.3750842	-.0292337	.3046191	.0075691	.2459655	.0382028	- .6810840	.5223855	- .6858705	.5248854
15	.4869490	-.0616950	.4105244	-.0258545	.3308796	.0114960	.2769251	.0367988	- .7496077	.5182062	- .7556702	.5210494
16	.4808173	-.0647359	.4007441	-.0261992	.3243656	.0105595	.2676444	.0278477	- .7338221	.5198331	- .7397490	.5226855
17	.4440771	-.0626419	.3735555	-.0262266	.3045745	.0093932	.2441314	.0406043	- .6806540	.5181369	- .6856842	.5207343
18	.4686363	-.0630136	.3939321	-.0264008	.3166329	.0114837	.2666110	.0359997	- .7201201	.5196000	- .7256918	.5223307
Band 7												
19	1.0235090	-.1806238	.6710796	-.0610395	.3950394	.0326245	.1847678	.1039723	-1.1279964	.5494111	-1.1463995	.5556555
20	.9497854	-.1754252	.6131391	-.0541723	.3627625	.0360079	.1800079	.1018317	-1.0464153	.5435621	-1.0592794	.5481956
21	.8628369	-.1793272	.5684921	-.0612958	.3313305	.0338047	.1628175	.1013777	- .9538993	.5491753	- .9715794	.5562648
22	.9447533	-.1753371	.6083295	-.0535507	.3690969	.0330526	.1884683	.0984407	-1.0464935	.5455005	-1.0641546	.5518939
23	.9123761	-.1771896	.5946172	-.0574325	.3495100	.0349436	.1724302	.1016812	-1.0061617	.5458690	-1.0227709	.5521286
24	.9417751	-.1685808	.6233358	-.0552244	.3641466	.0370401	.1928612	.0980132	-1.0506973	.5406870	-1.0714226	.5480649

Table C-6 .——Landsat 3 C_i's and D_i's: High gain decompressed.

Sensor	D_1	C_1	D_2	C_2	D_3	C_3	D_4	C_4	D_5	C_5	D_6	C_6
Band 4												
1	.5247137	-.1390668	.4431337	-.0915327	.3576929	-.0417495	.2731203	.0075287	-.7900258	.6269886	-.8086318	.6378295
2	.6272712	-.1385278	.5143536	-.0835882	.4318466	-.0434456	.3439335	-.0006716	-.9490855	.6284384	-.9683148	.6377941
3	.6284514	-.1389027	.5095294	-.0810795	.4347455	-.0447175	.3431122	-.0001633	-.9492778	.6282305	-.9665548	.6366310
4	.5970588	-.1364253	.4858097	-.0799507	.4114310	-.0421927	.3313130	-.0015217	-.9032097	.6251735	-.9223989	.6349147
5	.6181401	-.1444781	.5175102	-.0938253	.4167681	-.0431162	.3267191	.0022107	-.9264259	.6329890	-.9527088	.6462187
6	.6087410	-.1395825	.4994858	-.0846178	.4265492	-.0479243	.3318703	-.0002923	-.9243167	.6316776	-.9243251	.6407375
Band 5												
7	.5518665	-.1560426	.4546716	-.0992072	.3626205	-.0453791	.2734180	.0067823	-.8148912	.6431835	-.8276793	.6606611
8	.5910916	-.1513963	.4867696	-.1034963	.3824342	-.0455884	.2885204	.0065343	-.8674901	.6481347	-.8813231	.6558121
9	.5953695	-.1629270	.4849899	-.1018216	.3833493	-.0455539	.2945392	.0036108	-.8675578	.6469432	-.8906841	.6597456
10	.6206412	-.1576287	.5104772	-.1000667	.3011881	-.0430135	.3041369	.0077498	-.9086376	.6414458	-.9278972	.6515092
11	.5584256	-.1580148	.4660206	-.1017851	.3645390	-.0433260	.2709705	.0105744	-.8216435	.6399757	-.8383080	.6495750
12	.6360582	-.1636969	.5194108	-.1031114	.4058478	-.0441277	.3075250	.0069403	-.9266692	.6479717	-.9421678	.6560216

APPENDIX D

RBV RADIOMETRIC CORRECTION

The radiometric correction of the RBV is functionally computed in two parts. The first part is the radiometric-correction-coefficient computation. This includes preprocessing of Radio Corporation of America (RCA) lamp radiometric data to get an initial correction, and occasional (once a week) processing of radiometric-calibration-lamp images from the spacecraft to update the correction coefficients. The second part is the radiometric-correction-coefficient application; this is the radiometric correction of RBV imagery.

The radiometric correction of RBV imagery is complicated by the fact that the response of the camera is a two-dimensional, spatially varying function. The correction technique divides the RBV image into small zones within which a constant gain and bias correction can be applied with acceptable small error.

Inputs for the correction process are:

- Uniform-radiance RCA lamp data (taken prior to launch) at ten different radiance levels and used to get an initial radiometric correction. The RCA lamp data is provided in the form of voltages averaged over an 18 x 18 grid of small neighborhoods.
- Calibration-lamp data used to update the radiometric-correction coefficients.
- Radiometrically uncorrected RBV images.

Outputs are:

- Two 20 x 20 arrays of corrected nominal calibration-lamp-image (CLI) radiometric intensities
- Coordinates of horizontal and vertical radiometric-correction-zone boundaries.
- Gain and bias coefficients for each radiometric-correction zone
- Radiometrically corrected RBV images

PREPROCESSING RCA LAMP DATA

Radiometric-correction-coefficient computation begins with the preprocessing of the RCA lamp data (figure D-1). Using the 18 x 18 array of voltage readings provided, the outermost rows and columns of the 18 x 18 array are repeated to produce a 20 x 20 array of average intensities.

From the ten levels provided, those levels that represent saturation of the camera are eliminated—— only levels from the linear-response region are of interest. A linear-least-squares estimate of the gain and bias correction values at each of the 20 x 20 data points is computed.

ZONING THE IMAGE

Zoning of the image is described in figure D-2. Global, eighth-order bivariate polynomials of gain and bias are computed as least – square estimates over the 20 x 20 array of gains and biases.

The image is zoned as two one-dimensional problems–– first the horizontal zones are computed and then the vertical zones. Horizontal and vertical zoning are performed in the same manner. For each of the several lines in the

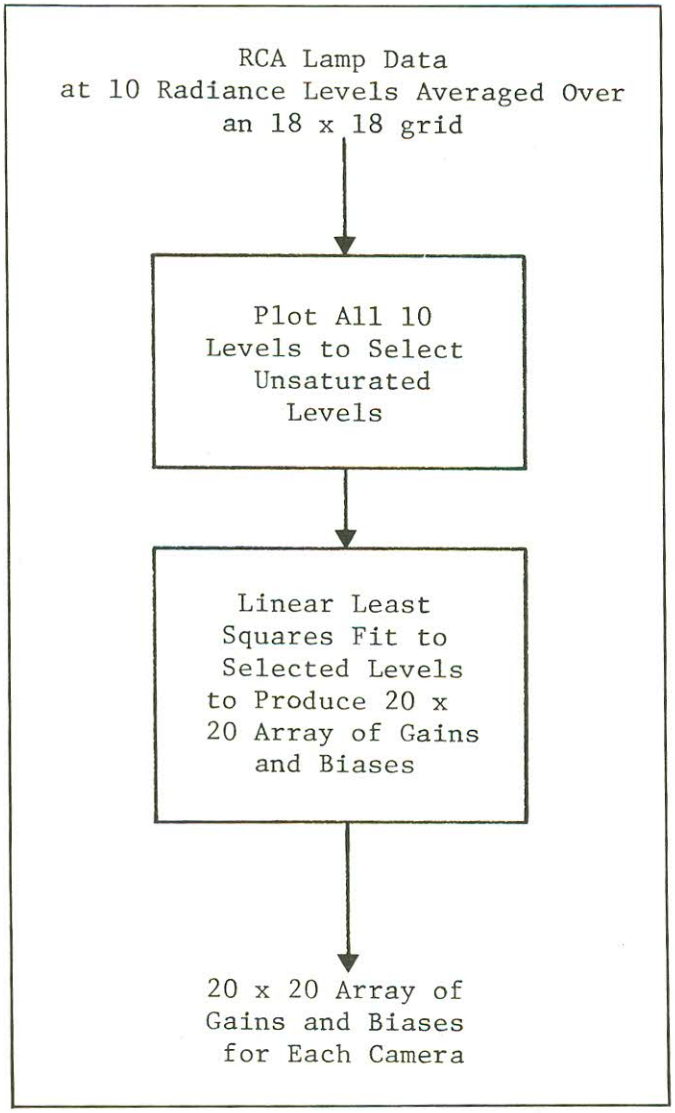


Figure D-1 .––Preprocessing of RCA lamp data.

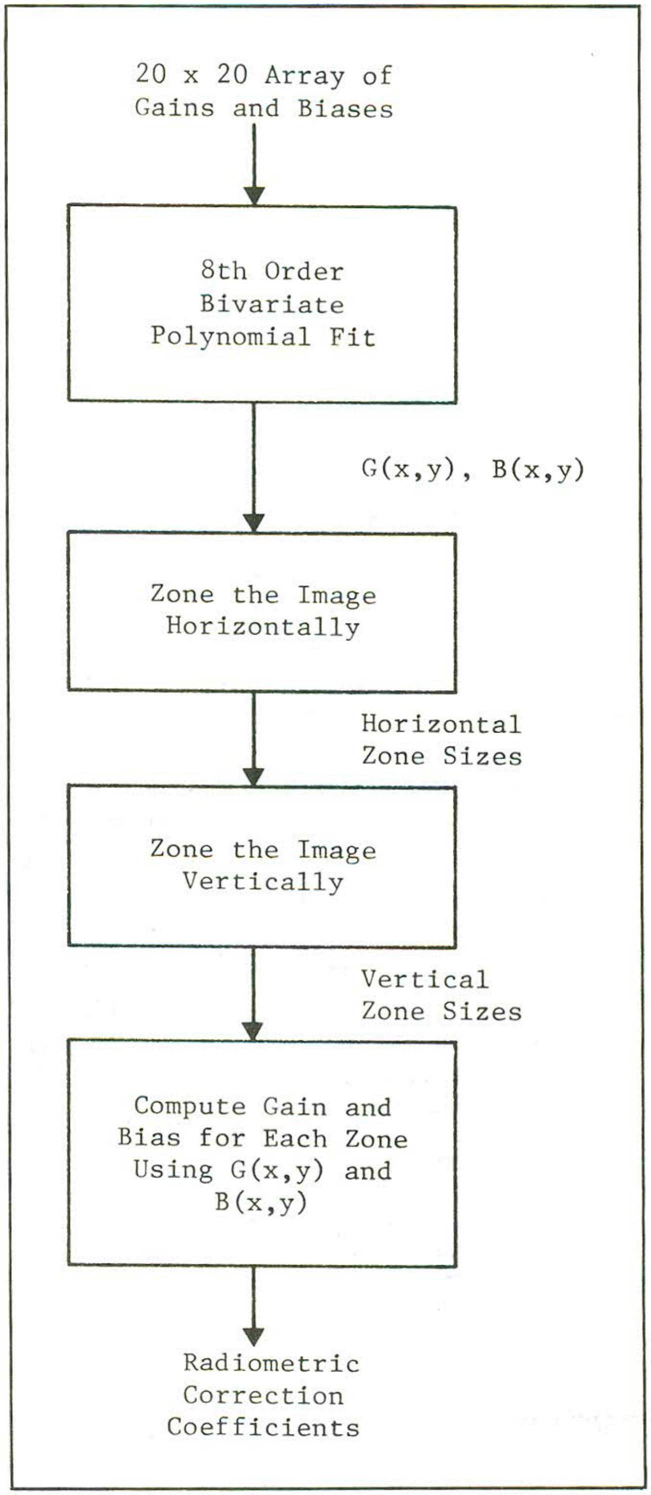


Figure D-2 .––Zoning the image.

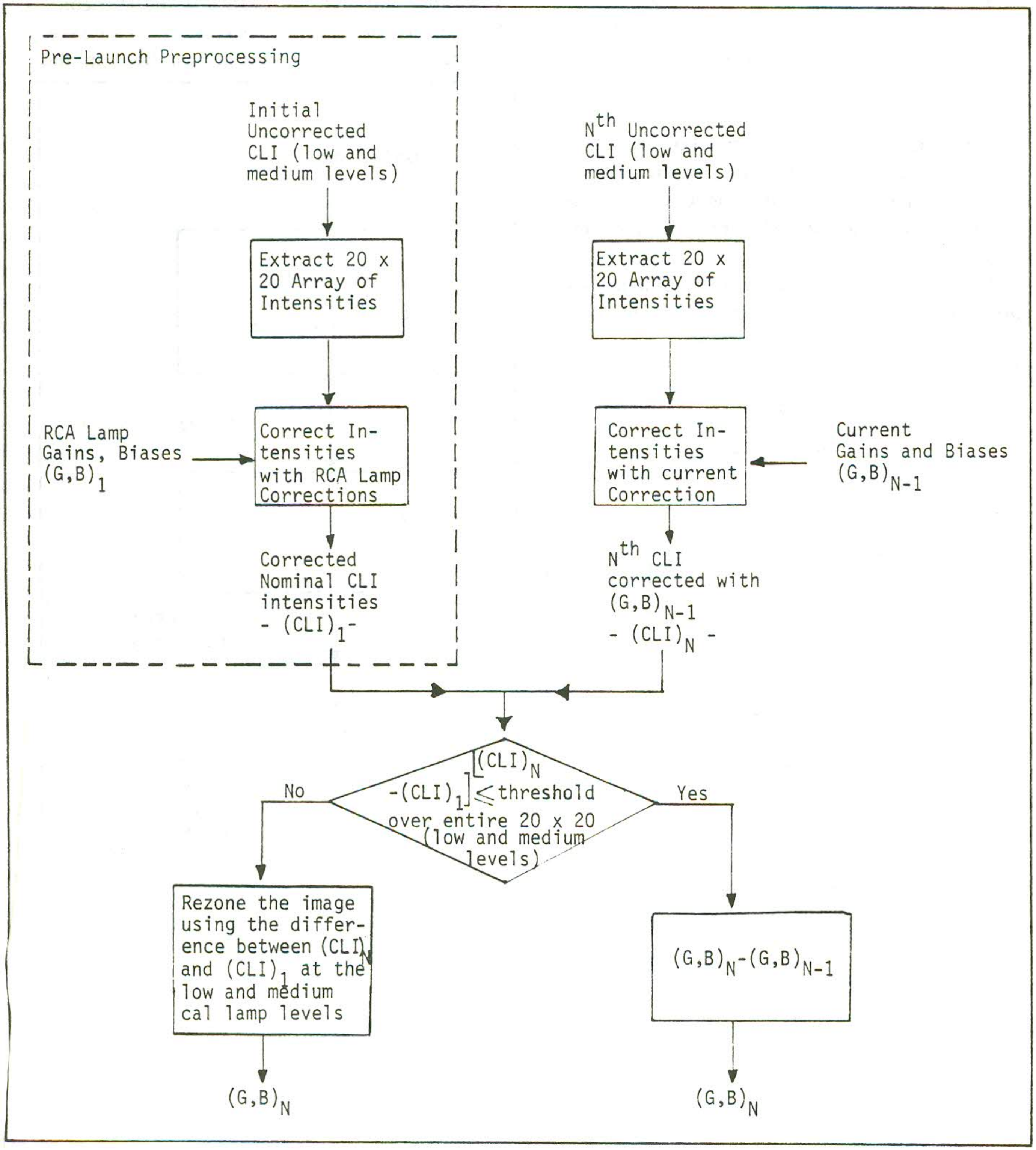


Figure D-3 .—Calibration-lamp image processing.

image, the zone sizes (as determined by measuring the radiometric distortions along each line) are computed. The final zone size used is the smallest of the zones computed in each line. The zone boundaries are stored on the MDP system disk.

For each zone, gain and bias coefficients are computed, using the eighth order gain and bias polynominal and the coordinates of the center of the zone. These coefficients are also stored the MDP system disk.

CALIBRATION LAMP IMAGE PROCESSING

For subsequent calibration - lamp - image processing, the gain and bias polynominals are used to compute the gain and bias at the center of each 20 pixel x 20 pixel-intensity sampling array. These values of gain and bias are stored on the MDP system disk.

Calibration-lamp data are used to detect changes in RBV camera response and to update the radiometric-correction coefficients. The first calibration-lamp image is corrected using the RCA lamp coefficients and is used as a baseline from which all future camera-response changes are determined (figure D-3).

From the first calibration-lamp image (CLI), a 20 x 20 array of small (20 pixel by 20 pixel) subimages centered at the intensity sampling points, is extracted. An average intensity value is computed for each subimage. For each of the two intensity levels–– calibration zero and calibration one (calibration two tends to be saturated because of its high level)–– the 20 x 20 array of intensities is corrected using the gains and biases computed from RCA lamp data. The output of the preprocessing step is a 20 x 20 array of corrected nominal CLI intensities–– $(CLI)_1$ ––for each of two calibration levels. These arrays are stored on the MDP system disk.

After launch, a calibration-lamp image is processed as often as deemed necessary, and a 20 x 20 array of small subimages is extracted and averaged to produce a 20 x 10 array of intensities. These intensities are corrected using the current radiometric coefficients and tested against the corrected nominal CLI intensities. If the camera response has changed, a new 20 x 20 array of gains and biases is computed using the differences between current and corrected nominal CLI intensities, a new eighth order polynomials are computed, and the image is rezoned. The zoning technique is precisely the zoning of figure D-2 (the zoning that was done on the RCA lamp data). If the camera response has not changed, current zoning and coefficients are not changed.

RADIOMETRIC CORRECTION OF DATA

The radiometric correction of RBV images is performed by applying the gain and bias for a given zone to all the input-image-intensity values in that zone (figure D-4).

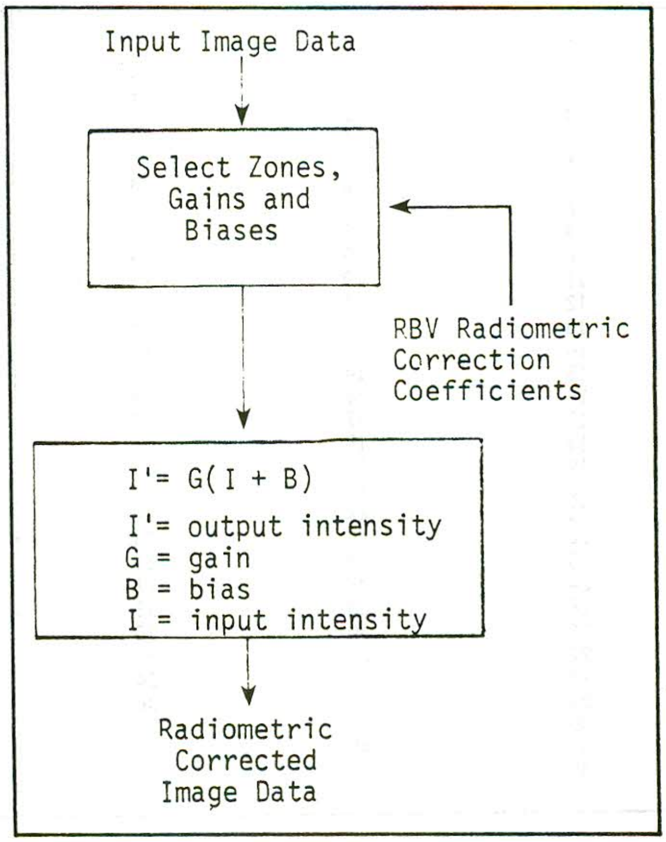


Figure D-4 .––Radiometric-correction-coefficient application.

APPENDIX E

MSS DECOMPRESSING TABLES

Tables E-1, E-2, and E-3 are used for decompressing the video data from bands four, five, and six. Bands seven and eight require no decompression.

The values of the compressed video data vary from 0 to 63; after decompression, the video–data values for seven-bit image pixels vary from 0 to 127. The decompressed values and gains and offsets are used to determine the calibrated values of the video data. To reverse the process and obtain compressed values from the de–compressed values on the CCT, the user must have the gain and offset values, in addition to the values in the decompression table. However, due to roundoff and truncation errors, the process is not absolutely reversible.

COMPRESSED QUANTUM LEVEL (6 BITS)	BAND 4 AND 6 EQUIVALENT LINEAR QUANTUM LEVEL (7 BITS)	BAND 5 EQUIVALENT LINEAR QUANTUM LEVEL (7 BITS)
0	0	0
1	1	1
2,3	2	2
4	3	3
5	4	4
6	5	5
7	6	6
8	7	7
9	8	8
10	9	9
11	10	10
12	11	11
13	12	12
14	13	13
15	14	14
16	16	16
17	17	17
18	18	18
19	19	19
20	21	21
21	22	22
22	24	23
23	25	25
24	27	27
25	29	28
26	30	30
27	32	32
28	34	34
29	36	36
30	38	38
31	40	39
32	42	41
33	43	43
34	45	45
35	47	47
36	49	49
37	51	51
38	53	53
39	56	54
40	58	58
41	61	60
42	63	63
43	66	66
44	69	69
45	72	71
46	75	74
47	78	77
48	81	80
49	83	83
50	86	86
51	89	88
52	92	91
53	95	94
54	98	97
55	101	100
56	104	104
57	106	107
58	109	109
59	112	112
60	115	115
61	118	117
62	121	120
63	124	122

Table E-1 .––Landsat 1 decompression values.

Table E-2 .--Landsat 2 decompression values

COMPRESSED QUANTUM LEVEL (6 BITS)	BAND 4 AND 6 EQUIVALENT LINEAR QUANTUM LEVEL (7 BITS)	BAND 5 EQUIVALENT LINEAR QUANTUM LEVEL (7 BITS)	COMPRESSED QUANTUM LEVEL (6 BITS)	BAND 4 AND 6 EQUIVALENT LINEAR QUANTUM LEVEL (7 BITS)	BAND 5 EQUIVALENT LINEAR QUANTUM LEVEL (7 BITS)
0	0	0	32	43	43
1	1	1	33	45	45
2	2	2	34	47	47
3	3	3	35	49	49
4	4	4	36	51	51
5	5	5	37	53	53
6	6	6	38	55	55
7	6	7	39	57	58
8	7	8	40	60	60
9	8	9	41	62	63
10	9	10	42	65	66
11	10	11	43	68	69
12	12	12	44	71	71
13	13	13	45	74	74
14	14	14	46	77	77
15	15	16	47	79	80
16	17	17	48	82	83
17	18	18	49	85	86
18	19	19	50	88	89
19	20	21	51	91	92
20	22	22	52	94	95
21	23	23	53	97	98
22	25	25	54	100	101
23	27	27	55	103	104
24	28	28	56	106	107
25	30	30	57	109	110
26	31	32	58	112	113
27	33	34	59	115	116
28	35	36	60	118	118
29	37	38	61	121	121
30	39	40	62	124	124
31	41	41	63	127	127

Table E-3 .——Landsat 3 decompression values

COMPRESSED QUANTUM LEVEL (6 BITS)	BAND 4 AND 6 EQUIVALENT LINEAR QUANTUM LEVEL (7 BITS)	BAND 5 EQUIVALENT LINEAR QUANTUM LEVEL (7 BITS)	COMPRESSED QUANTUM LEVEL (6 BITS)	BAND 4 AND 6 EQUIVALENT LINEAR QUANTUM LEVEL (7 BITS)	BAND 5 EQUIVALENT LINEAR QUANTUM LEVEL (7 BITS)
0	0	0	32	43	42
1	1	1	33	45	45
2	1	2	34	47	47
3	2	3	35	49	49
4	3	4	36	51	52
5	4	5	37	53	54
6	5	6	38	55	56
7	6	7	39	58	58
8	7	8	40	60	60
9	8	9	41	63	63
10	9	10	42	66	66
11	10	11	43	68	69
12	11	12	44	71	72
13	12	13	45	74	74
14	13	14	46	77	77
15	15	15	47	80	80
16	16	17	48	84	83
17	17	18	49	87	86
18	18	19	50	90	89
19	20	20	51	92	92
20	22	22	52	95	95
21	23	23	53	98	98
22	25	25	54	101	101
23	26	26	55	104	104
24	28	28	56	108	107
25	30	30	57	111	110
26	32	32	58	114	113
27	34	34	59	117	116
28	35	35	60	120	119
29	37	37	61	123	122
30	39	39	62	125	125
31	41	41	63	127	127

APPENDIX F

CORRESPONDENCE BETWEEN CCT IMAGE DATA AND GROUND AREA COVERED

The MSS sensor operates at a rate that produces pixel overlap within scan lines. The within-line pixel overlap varies due to variation in mirror velocity. The effect of this variation is represented in figures F-1 through F-3. For CCTs with data that have not been geometrically corrected, as was the case for all CCTs produced in the Landsat-1 and –2 "X-Document" format (Thomas, V.L., 1975): individual pixels reflect this overlap, which must be taken into account when determining ground area covered. The geometric-correction process, however, creates a new pixel array which represents, in a one to one aspect ratio, an image in a selected map projection, with each corrected pixel covering a unique ground area of 57 square meters.

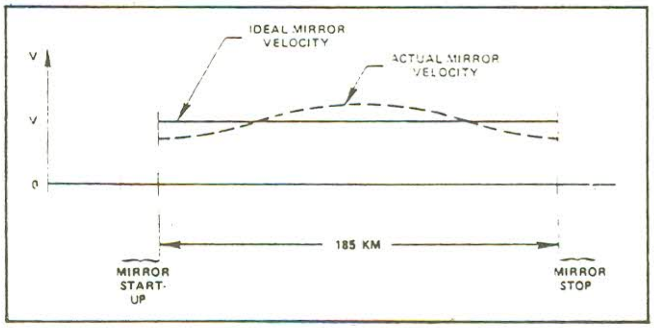


Figure F-1 .——Comparison of the constant mirror velocity and the variable mirror velocity.

It should also be noted that with CCT data

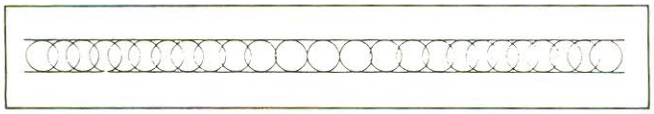


Figure F-2 .––Overlay of pixels, corresponding to a variable mirror velocity.

presented as described in this document, there is a one-to-one correspondence between the scan lines and pixels of the digital data and the scan lines and pixels of the related photographic data. This was not true of the earlier CCTs, because the geometric corrections were applied to the photographic data as part of the image-exposure process, and not to the digital image data. The resulting photographic image had fewer scan lines per scene than did the CCT.

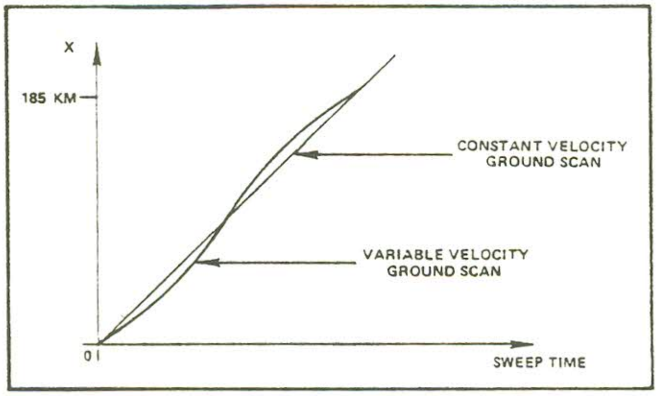


Figure F-3 .––Comparison of distance covered on the ground for a constant mirror velocity and a variable mirror velocity.

RBV data does not require the type of overlap correction discussed for MSS data; however, geometric corrections are made for effects of aspect distortions, Earth curvature, satellite-altitude variations, and so on, so that the corrected RBV image data represents the same type of projection as for MSS, with each pixel covering a unique ground area of 19 ground meters.

APPENDIX G

MAP PROJECTIONS

The Universal Transverse Mercator (UTM) projection has been found useful as a means of providing numerical geographic data to be combined with Landsat imagery. A worldwide system of zones has been set up for this projection; the transformation equations are fairly easy to put into computer language; and the residual errors are small enough to be nearly negligible over the area of a Landsat-image zone.

Approximately 60 countries publish maps in this projection, especially smaller scale (larger area) maps. The USSR, China, and associated countries use the Gauss-Kruger projection which is the same as the UTM except that the scale factor on the central meridian is 1.0000 instead of 0.9996.

The Space Oblique Mercator (SOM) projection is being developed as the standard map projection for Landsat imagery. This projection is developed along the lines of M. Hotine's Oblique Mercator projection with account taken of the Earth-rotation effects. A preliminary version is given by A. P. Colvocoresses (1974); the precise mathematical formulation and constants are now being developed and are expected to be available in early 1978.

Richardus and Adler, 1972, provides a good, intermediate-level test on map projections with a mathematical development of the subject using differential and integral calculus.

Thomas, 1952, gives a unified treatment of projections from the standpoint of mapping upon the complex variable plane. The final results are given in considerable detail for those who are unwilling to follow the detailed derivations.

The appendix of Adams, 1949, provides the simplest form for computer calculation of S_P, the geodetic distance along the meridian from the Equator to the point P.

"The Universal Grid Systems" is devoted to the development of a worldwide grid system employing the Polar Stereographic projection in the Polar regions and UTM elsewhere.

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